NISTIR 7192

2004 Conference on IEEE 1588, Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

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NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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2004 Conference on IEEE 1588, Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

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November 2004

U.S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary
TECHNOLOGY ADMINISTRATION
Phillip J. Bond, Under Secretary of Commerce for Technology
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Hratch G. Semerjian, Acting Director

2004 Conference on IEEE 1588, Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

Co-sponsored by
NIST and IEEE Instrumentation and Measurement Society

NIST
Gaithersburg, Maryland
September 27-29, 2004

Conference Sessions: Lecture Room A
Plug-fest Demonstration: Lecture Room B

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AGENDA

Monday, September 27, 2004

- 8:30-9:00 AM: Meeting of Plug-fest participants. This session is open only to Plug-fest participants.
- 9:00 AM – 12:15 PM: Plug-fest integration tests. This session is open only to Plug-fest participants.
- 10:30 AM: Morning coffee break
- 12:15-1:15 PM: Lunch at NIST cafeteria (not included in registration fee)
- 1:15-5:00 PM: Plug-fest integration tests. This session is open only to Plug-fest participants.
- 12:30-1:15 PM: Tutorial participants registration
- 1:15-5:00 PM: IEEE 1588 Tutorial: John C. Eidson, Agilent Technologies
- 3:00 PM: Afternoon refreshment break

Tuesday, September 28, 2004

- 8:00 AM: Bus leaves conference hotel for NIST facility
- 8:30-9:00 AM: Continental breakfast, meet other attendees, pick up conference badges and material. (Allow 30 minutes from arrival at the main gate due to security and parking)
- 9:00-9:15 AM: **Conference Opening**
  Moderator: Kang Lee, NIST
  - Welcome from Dr. Hratch G. Semerjian - Acting Director of NIST
  - Administrative details
- 9:15 AM to 10:30 AM: **Technical Paper Presentations Session I**
  Moderator: Oyvind Holmeide, OnTime Networks AS
  - 9:15-9:40 AM: **A Flexible and Scalable Network Simulation Environment for Clock Synchronization:** Roland Hoeller, Georg Gaderer, Hannes Muhr, Nikolaus Kero, Vienna University of Technology and Oregano Systems
  - 9:40-10:05 AM: **Implementation Design and Performance Issues:** Hans Weibel, Dominic Béchaz, Zurich University of Applied Science
  - 10:05-10:30 AM: **Industrial Automation Requires Synchronization of Line Topology:** Antonius Boller, Siemens
- 10:30 - 10:50 AM: Morning coffee break
- 10:50 AM-12:30 PM: **Technical Paper Presentations Session II**
  Moderator: John C. Eidson, Agilent Technologies
  - 10:50-11:15 AM: **IEEE 1588 Ethernet Switch Transparency:** Sven Nylund, Oyvind Holmeide, OnTime Networks AS
  - 11:15-11:40 AM: **Bridging Networks with PTP:** Karl Weber, Siemens, Jürgen Jasperneite, Phoenix Contact GmbH
  - 11:40 AM-12:05 PM: **Implementation Results of an IEEE 1588 Boundary Clock:** Dirk S. Mohl, Hirschmann Electronics
  - 12:05-12:30 PM: **PHYs and Symmetrical Propagation Delay:** Thomas Müller, Zurich University of Applied Science, Alexander Ockert, Hilscher, Hans Weibel, Zurich University of Applied Science
- 12:30-1:30 PM: Lunch at NIST cafeteria

- 1:30-3:10 PM: **Standards And Business Related Activities**
  Moderator: Kang Lee, NIST

  - 1:30-1:50 PM: Report of the User Requirements Task Group: Silvana Rodrigues, Zarlink Semiconductor, Steve Zuponcic, Rockwell Automation
  - 1:50-2:10 PM: Report of the Technical Extensions Task Group: John C. Eidson, Agilent Technologies
  - 2:10-2:30 PM: Report of the Conformance Task Group: Oyvind Holmeide, OnTime Networks AS
  - 2:30-2:50 PM: Presentation of Draft PAR: John C. Eidson, Agilent Technologies
  - 2:50-3:10 PM: Proposal for IEEE 1588 Trade Association: John C. Eidson, Agilent Technologies

- 3:10-3:30 PM: Plug-fest Introduction: Objectives, Participants, and Results
  Moderator: Anatoly Moldovansky, Rockwell Automation

- 3:30-3:45 PM: Afternoon refreshment break

- 3:30-5:00 PM: Attendees view and discuss Plug-fest in Lecture Room B

- 5:15 PM: Bus leaves NIST for conference hotel

- 6:30-9:00 PM: **Conference Reception And Dinner**

Bus leave conference hotel restaurant
  - 6:45- 7:15 PM: No-host cash bar
  - 7:15 PM: Conference Dinner
  - 9:00 PM: Bus leave restaurant for conference hotel

Wednesday, September 29, 2004

- 8:00 AM: Bus leaves conference hotel for NIST facility
- 8:30-9:00 AM: Continental breakfast
- 9:00 AM to 10:15 AM: **Technical Paper Presentations Session III**
  Moderator: John D. McKay, Progeny Systems

  - 9:00-9:25 AM: IEEE 1588 over IEEE 802.11b for Synchronization of Wireless Local Area Network Nodes: Afshaneh Pakdaman, Todor Cooklev, San Francisco State University; John Eidson, Agilent Technologies
  - 9:25-9:50 AM: High Accuracy Clock Synchronization Using IEEE 1588: Pritam Baruah, Pruthvi Chaudhari, Paul Corredoura, John C. Eidson, Andrew Fernandez, Bruce Hamilton, John Stratton, Dieter Vook, Agilent Technologies
  - 9:50-10:15 AM: Primary Timing Reference Sources for IEEE-1588 Systems: Paul Myers, Spectracom

- 10:15 - 10:35 AM: Morning coffee break

- 10:35 AM to 12:15 PM: **Technical Paper Presentations Session IV**
  Moderator: Anatoly Moldovansky, Rockwell Automation

  - 10:35-11:00 AM: DeviceNet Adaptation of IEEE 1588: Ron Holl, Dave VanGompel: Rockwell Automation
  - 11:00-11:25 AM: Hardware Assisted IEEE1588 Implementation in a Next Generation Intel Network Processor: Puneet Sharma, Intel Corporation
  - 11:25-11:50 AM: Interfacing Mil Standard Equipment to an IEEE 1588 Enabled Ethernet Network: John D. MacKay, Progeny Systems
  - 11:50 AM-12:15 PM: Automatic Test Systems using LAN-based Synthetic Instruments and the Role of IEEE 1588: John Stratton, John Swanstrom, Agilent Technologies

- 12:15-1:15 PM: Lunch at NIST cafeteria

- 1:15 to 2:05 PM: **Technical Paper Presentations Session V**
  Moderator: John C. Eidson, Agilent Technologies

  - 1:15-1:40 PM: **IEEE 1588 in Telecommunication Applications:** Dave Tonks, Semtech
  - 1:40-2:05 PM: **IEEE 1588 Telecom Use Cases and L2 Ethernet Multicast:** Glenn Algie, Nortel Networks

- 2:05-3:50 PM: **Discussion Session**
  Moderator: Kang Lee, NIST & John Eidson, Agilent Technologies

  - 2:05-2:30 PM: **Discussion & Attendee Feedback on IEEE 1588 PAR**
  - 2:30-3:00 PM: **Discussion & Attendee Feedback on IEEE 1588 Trade Association**

- 3:00-3:20 PM: Afternoon refreshment break & networking

  - 3:20-3:50 PM: **Open Discussion on Other Issues**

- 3:50-4:00 PM: **Closing Comments**
  - Kang Lee & John Eidson

- 4:00 PM: Conference adjournment

- 4:30 PM: Bus leaves NIST for conference hotel

EXECUTIVE SUMMARY FROM THE CONFERENCE CO-CHAIRS

The conference was hosted by NIST on September 27-29, 2004 and was cosponsored by the Institute of Electrical and Electronics Engineers (IEEE) Instrumentation and Measurement Society. Acting Director of the National Institute of Standards and Technology (NIST), Dr. Hratch Semerjian, opened the conference with a warm welcome. Dr. Semerjian spoke of the importance of standards on components and system interoperability and his assertion of interoperability's role in the expansion of the PC market to its grand scale today. Dr. Semerjian described how standards are basic to the culture of NIST. Pursuing device and system interoperability based on standards is one of NIST's goals. More than seventy attendees participated in the conference, coming from diverse areas such as instrumentation and measurement, industrial automation, aerospace, power generation, semiconductor manufacturing, and telecommunication.

The three-day event began with a tutorial on the IEEE 1588 standard. The tutorial was unexpectedly well attended by more than sixty percent of the attendees. The main conference started on the second day. The interoperability of components and devices was demonstrated by seven companies and a university in an afternoon session informally dubbed the "Plug-fest." The devices were built to IEEE 1588 specifications, and showed that they could be synchronized to a master clock to sub-microsecond accuracy. The interoperability demo was led by Anatoly Moldovansky of Rockwell Automation, with participation from Agilent Technologies, Hirschmann Electronics, OnTime Networks AS, Rockwell Automation, Semtech Corp, Siemens, and Zurich University of Applied Sciences.

Participants were impressed with the smoothness and outcome of the interoperability demonstrations. Some components and systems were able to achieve clock synchronization to within +/- 40 nanoseconds based on a master clock signal from a global positioning system (GPS) antenna located on the lawn outside the conference facility. This illustrated the effectiveness of the 1588 standard and the ease with which devices can be built to its specifications.

The technical sessions covered subjects such as: primary timing reference sources for IEEE 1588 systems; high accuracy clock synchronization down to a nanosecond for precision measurements; network simulation environment for clock synchronization; device and microchip requirements; and adaptation, implementation, and application of IEEE 1588 in industrial automation, military, and telecommunications. A presentation by a graduate student on the application of IEEE 1588 for the synchronization of wireless local area network nodes based on 802.11b created quite a discussion. The field of wireless communications is of great interest to the attendees, who expressed a wish to see more detailed results in this area at the next conference.

As a result of the 2003 IEEE 1588 Workshop, three task groups were formed to address the issues of user requirements, technical extensions, and conformance of the IEEE 1588 Standard. The results of these three task groups were presented at the conference. These results were reflected in the presentation of a potential draft project authorization request (PAR) to IEEE and the possibility of forming an IEEE 1588 user group or trade association. An open forum was held on the last day of the conference to further discuss the issues of creating a PAR to revise the IEEE Std 1588-2002 Standard and the formation of a user or trade group to promote the standard and facilitate interoperability tests, and of enhancing the standard to expand its coverage from the instrumentation and measurement to other industries such as industrial automation and telecommunications.

Based on the feedbacks of the attendees, there was overwhelming consensus to reopen the IEEE 1588 standard to include:

1. Resolution of known errors,
2. Conformance enhancements,
3. Enhancements for increased resolution and accuracy,
4. Improvements to system management capability,
5. Mapping to DeviceNet,
6. Modifications for variable Ethernet headers (Annex D),
7. Prevention of error accumulation in cascaded topologies,
8. Mapping to Ethernet layer-2 small frame, shorter sync_interval,
9. Extensions to enable implementation of redundant systems, and
10. Improvements to extension mechanism.

If the standard is reopened some attendees suggested that the following additional items be considered as part of the scope:

- Alignment of IEEE 1588 and NTP stratum,
- Clock ID (identification) alignment with telecom T1.101 G.812,
- Security considerations- currently it is possible to take over the GR Role, e.g. with preferred master" or to manipulate sync packets, security IPv6 should be considered for backward compatibility, and there is a need to scope the problem and begin to get around it,
- Internet protocol version 6 (IPv6) Authentication - any IPv6 issues beyond Ethernet header size,
- Authentification for network security, IPv6 is essential or we will development a proprietary protocol version by necessity, or layer-2 mapping,
- Backward compatibility with current standard as its defined today,
- IEEE 1451 TEDS (transducer electronic data sheets)-like information on clock parameters. Better ID of stratum and source,
- Main point is authentication security. Other protocols do this at layer-3. However, authentification signature is large and it grows over time. Further, modification of packets violates authentication signatures or they need to be recalculated. At layer-3 IEEE 1588 should not do its own security. This is redundant and risky.
- Metadata format to allow description of oscillator and time source-ups receiver, vendor extensions for management information (MIB) for the simple network management protocol (SNMP), vendor extensions for metadata,
- Shouter frames and variable sync internal with unicort option will be vital to wireless sensor nets,
- Best master group,
- Some goals may be harder to achieve than others. Consider formulating more than one PAR,
- Inclusion of sync or management messages that permit a grand master to discover the time error of each slave. A message that can be decoded to produce a hardware interrupt to allow a MC (master clock) in a computer without a real-time OS (operating system) to execute an emergency operation in real time.
- Mapping to the control area network (CAN) open, and
- SNMP as a requirement for system management.

Conference Proceedings

The proceedings for the conference will be published as a NISTIR (internal report) before distribution. They will be posted in the IEEE 1588 website at http://ieee1588.nist.gov as soon as it is approved for publication by NIST.

Future Workshop

There was brief discussion on the plan for a future IEEE 1588 conference. Most attendees wanted to have another one. Location will be either at NIST or in Europe, which is to be determined. More detailed plans for the next workshop will be presented in the spring of 2005.

ABSTRACTS

Authors	Company	
Ron Holl, Dave VanGompel	Rockwell Automation	**DeviceNet Adaptation of IEEE-1588** DeviceNet is an extremely popular device level industrial network and is ideal for many applications requiring synchronized time, yet there is no current mechanism to accomplish this. This paper describes how DeviceNet will provide this function by adapting it to IEEE-1588 as a standardized PTP network technology. The adaptation includes selection of a message timestamp point, specification of the UUID, definition of both the PTP message format and PTP addressing on the subnet, and integration into the DeviceNet architecture.
Roland Hoeller, Georg Gaderer, Hannes Muhr; Nikolaus Kero	Vienna University of Technology Oregano Systems	**A Flexible and Scalable Network Simulation Environment for Clock Synchronization** The problem of synchronization of clocks in distributed systems has received much scientific attention throughout the last decades. A variety of algorithms has been published and issues like fault tolerance or achievable accuracy have been addressed. Nevertheless most applications found themselves sufficiently well synchronized by using means like the Network Time Protocol (NTP) or the Global Positioning System (GPS). Not only the recent interest in using Ethernet for industrial automation or even in sensor networks, but also the advent of the Institute of Electrical and Electronics Engineer's (IEEE) Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems (IEEE 1588) let high accuracy clock synchronization be a new discussed under the light of new applications and technical constraints. This paper presents a flexible and scalable network simulation environment, which allows for detailed and fast investigation of the major parameters of clock synchronization for any given network technology or topology. The simulation environment's architecture will be presented and simulation results together with their possible influences on existing technology or standards will be discussed.
Pritam Baruah, Pruthvi Chaudhari, Paul Corredoura, John C. Eidson, Andrew Fernandez, Bruce Hamilton, John Stratton, Dieter Vook	Agilent Technologies	**High Accuracy Clock Synchronization using IEEE 1588** There exist applications in the field of measurement instrumentation, military systems, and telecommunications with synchronization accuracy specifications extending to the nanosecond or sub-nanosecond range. This paper discusses the practical difficulties in achieving this level of synchronization and proposes extensions to IEEE 1588 to make this possible. Experimental results on prototype implementations will be discussed.

Afshaneh Pakdaman, Todor Cooklev; John Eidson	San Francisco State University Agilent Technologies	**IEEE 1588 over IEEE 802.11b for synchronization of wireless local area network nodes** IEEE 1588 is a new standard to synchronize independent clocks running on separate nodes of a distributed measurement and control system to high degree of accuracy. It used a precision-time protocol (PTP). In this paper it is advanced a method to implement clock synchronization over IEEE 802.11b Wireless LAN (WLAN). Practical experiments are presented. One conclusion is that IEEE 1588 can be implemented over 802.11b with an accuracy of 400ns.
Puneet Sharma	Intel Corporation	**Hardware Assisted IEEE1588 Implementation in a Next Generation Intel Network Processor** This paper will describe the hardware-assisted IEEE1588 implementation in a future planned Intel® network processor. A brief overview of the IEEE1588 standard is provided, with particular emphasis on Ethernet applications. The general pros and cons of purely hardware vs. software-oriented IEEE1588 implementations are also discussed and applied to Intel's co-hardware and software IEEE1588 implementation. A detailed description of the IEEE 1588 hardware logic and the Intel XScale® core-based software programming model is included. Finally, some examples of targeted industrial applications for IEEE1588 are described. Note regarding the 20-minute paper presentation at the Conference: The 20-minute presentation will NOT include a brief overview of the IEEE1588 standard as attendees should be familiar with the standard.
Hans Weibel	Zurich University of Applied Science	**Implementation design and performance issues** There exist applications where independence of specialized hardware is more important than accuracy. The Zurich University of Applied Sciences has evaluated the performance of software based time stamping methods. The test setup consists of an IEEE 1588 implementation which is capable to deliver three time stamps per transmission/reception of time critical messages simultaneously: The first time stamp is taken by hardware at the MII, the second at the entry point of the network interface driver's interrupt service routine and the third one is delivered by PCAP. A comparison of the time stamps allows the performance of different methods to be evaluated. The PTP protocol engine is able to select one of the three available time stamps as the source to calculate offset and delay. The synchronization behaviors and accuracy of different configurations can be analyzed. An interesting configuration is a hardware based master clock (e.g. a boundary clock located in a switch) combined with purely software based slave clocks.
Antonius Boller	Siemens	**Industrial automation requires synchronization of line topology** The high data transfer rate attainable through the Ethernet's physical properties opens new dimensions for real-time applications. A future-oriented concept must have at its core a wide, generally accepted basis, and must be expandable. Seen from this point of view, there is no alternative to switching technology. The advantages of higher data transfer rates, full-duplex communication and collision-free access, however, are bought at the expense of

an unsymmetrical communication. Due to the fact that frames are buffered in the switch and the length of time they remain there depends on the network load this may even lead to frame loss in critical situations. This is a most unfortunate peculiarity in the case of real-time applications and the reason why it is not possible to fulfil the requirements of the switched-Ethernet-based motion control applications with the existing IEEE 1588 method. Especially in the industrial automation a basic requirement of the network is the ability for line topology. Hence a cascade of switches has to be synchronized. With today's IEEE 1588-method the required accuracy for a line of switches causes problems.

The presentation shows the need for real time Ethernet in the industrial automation and the problems when using IEEE 1588 for synchronization issues in this area. Furthermore it shows a method which solves these problems.

John D. MacKay — **Progeny Systems**

Interfacing Mil Standard Equipment to an IEEE 1588 Enabled Ethernet Network

This paper will discuss the unique requirements for interfacing a number of military standard devices to a 1588 network. The current trend for signal processing on military platforms is to maximize the usage of Commercial Off the Shelf (COTS) products rather than developing full mil-grade equipment. This approach provides a great deal of advantage to the system developer, because it provides access to a variety of low cost high performance devices that have a great deal of field experience and customer support. The drawbacks to this approach occur at the edges of the system, where these COTS devices must interface either with very specialized sensor and transducer equipment, or with 'legacy' standard busses and protocols.

A COTS system with Ethernet as the core network can be subject to this issue, but this can be compounded by the need to provide highly accurate timestamp information via 1588. Typically the legacy devices are clocked by their own internal timing, and drive the system time via COTS interface cards. Timestamps therefore occurred at the 'front end' of the process string, and became embedded in the data stream. While the insertion of timestamp data in a 1588-enabled system would likely be the same, the source of time would need to be either a 1588 network device or a legacy device modified to be 1588-enabled. There are issues with both of these solutions.

These options will be discussed for this use case as well as others. A use case that would require the 1588 protocol to be implemented on a mil-standard asynchronous bus will also be discussed.

Dirk S. Mohl — **Hirschmann Electronics**

Implementation Results of an IEEE 1588 Boundary Clock

Boundary clocks are necessary to distribute the precise time over network components like switches and routers. To build such a boundary clock inside an Ethernet switch beside the standard functionality several additional points have to be taken into account.

Ethernet Switches typically use SNMP as management protocol, so relevant parts of the IEEE1588 managed objects have to be accessible through SNMP. Also a switch often gets or provides time over SNTP. The question now is how to combine these two protocols and not to loose IEEE1588 precision. The more IEEE 1588 Switches are used the network the more the issue of cascading Boundary Clocks and its effect on precision and system startup has to be analyzed.

The necessity of cascading boundary clocks often is imposed from the network topology of the application. One aspect of using IEEE1588 is derived from Industrial Automation Technology. There IAONA, the independent platform organization for Industrial Ethernet may give ideas about usage, applications and topologies of the network.

Sven Nylund
Oyvind Holmeide
OnTime Networks AS

IEEE 1588 Ethernet switch transparency- No need for Boundary Clocks!

One of the main IEEE1588 properties is related to the handling of variable network latency between the Grand Master clock and the Slave clocks. I.e. the network load dependable latency through the network elements (e.g. Ethernet switches). This is handled if IEEE1588 Boundary clocks are used on the network path between Grand Master and the Slave clocks. However, this means that each network element in the network must support full Master, Slave and the Best Master Algorithm with increased complexity and cost as the result.

A simpler and cheaper approach is based on using network elements with IEEE1588 transparency and still achieves the same level of timing accuracy on the Slave clocks and being compliant with the IEEE1588 standard. This paper describes the principles of a network element with IEEE1588 transparency.

Karl Weber
Siemens

Bridging Networks with PTP

Discuss influence of switches in networking today and how it correlates to 1588. General procedures running at switches and infrastructure of such switches. Discuss need for time synchronization in switches Propose Architecture for "PTP Bridges" that enhance accuracy and reduce resource utilization in switches. Criteria for a PTP Bridge protocol that will be accepted by most switch manufacturer

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Thomas Müller
Zurich University, Winterthur

PHYs and Symmetrical Propagation Delay

PTP requires a symmetrical propagation delay or at least a system with known differences between a pair of links. Ethernet Physical Layer transmitter/receiver are not symmetrical. The same can be found in cable specification.

Some parameter may not known and are not specified in the related standards nor by some device specifications. Measurement show a high accuracy but also some significant difference especially in case of auto-negotiation and auto-crossover.

A criteria list for transmitter/receiver is set up to achievable high precision time synchronization. I will do this together with other colleagues.

Dave Tonks
Semtech Advanced Communications Division, Southampton UK

IEEE 1588 in Telecommunication Applications

IEEE 1588 is being considered for various applications within telecommunication networks, including delivering a common time base across a network for billing purposes and for synchronizing service points which have become isolated by use of a packet network. This paper investigates a few of these applications and discusses a number of issues, including expected limitations on network topology, and known or likely performance goals, and, most importantly, probable barriers to adoption. The paper goes on to discuss how these issues could be tackled, and in particular how the current IEEE 1588 standard could be adapted to simplify its adoption in telecommunication applications.

The migration of telecommunication networks away from their traditional circuit-based architecture and towards an all-encompassing packet network has begun. The principal drivers behind this are significant cost-reductions in both capex and opex, and simpler roll-out of new services. When completed, it will be seen to have been a massive overhaul of networking technology, covering all aspects of the network, from switching and transmission to operational, administration and maintenance activities. However, many of the services which have been enjoyed for many years will continue to exist and these are not well served by packet networks. They have critical time dependencies which, if not satisfied, will cause the service to fail to maintain the high levels of customer satisfaction they enjoy today. The problem, then, is in finding ways to satisfy the critical time dependencies in a packet network. IEEE 1588 offers a cost-effective way to deliver timing in packet networks, providing certain limitations can be overcome.

Packet networks differ considerably from traditional circuit-switched networks. The possibility of departing from the 'fixed' route per call, and the use of service level agreements in which it is necessary to know not only just how much traffic of each particular type was delivered, but also how much of it met the delay targets, means that network operations such as traffic-counting have to be moved to the edge of the network. This demands that accurate time be made available right at the edge of the network. IEEE 1588 can provide that time.

Carrying time-dependent services in a packet network is often done using a circuit-emulation technique. But this is best done when a common clock is available at both ends of the connection. Traditional networks inherently provide this clock but packet networks cannot. Adaptive clocking techniques are available but suffer from network behaviors and can only offer a lower performance. Customer complaints could be common. Alternatively, IEEE 1588 can provide the common clock at the ends of the connection and so help maintain quality of delivery. This paper explores these, and other, applications.

John Stratton,
John Swanstrom,
Agilent Technologies

Automatic Test Systems using LAN-based Synthetic Instruments and the Role of IEEE 1588

With the current trend to drive down the total cost of ownership of Automatic Test Systems (ATS), industry standard open architectures have been seen as both a way of driving down the cost of test (for design and manufacturing) and reducing the size of the ATS platforms (eliminate the redundant hardware).

A LAN-based synthetic instrument architecture offers an alternative to the traditional approach that allows systems integrators and manufacturers to minimize the total cost of ownership from digital to the highest performance millimeter wave applications. IEEE 1588 is proposed as the long-term solution for synchronization is the LAN environment.

This paper will analyze the current trends in computer architectures and how it is used in synthetic instrument based ATSs. It will show how future trends in component technologies will drive how synthetic instruments might be designed. And finally, it will show how customers and instrument providers can quickly implement current capability and next generation test technology.

Paul Myers

Spectracom Corporation

Primary Timing Reference Sources for IEEE-1588 Systems

This presentation reviews and compares Primary Time Reference sources for IEEE 1588 systems. Primary Time Reference sources such as GPS, Loran and cellular GSM/CDMA are reviewed. The technical merits, characteristics, performance differences, costs applications and availability are contrasted. The use of these primary time references in the design of a grand master clock and resulting predicted precision of 1PPS outputs is examined. The application of various oscillator types to IEEE-1588 systems is compared in light of primary timing reference selection, and holdover performance.

TU WIEN

Oregano Systems

A Flexible and Scalable Network Simulation Environment for Clock Synchronization

Roland Höller, Georg Gaderer, Hannes Muhr, Nikolaus Kerö

ICT

Institute of Computer Technology

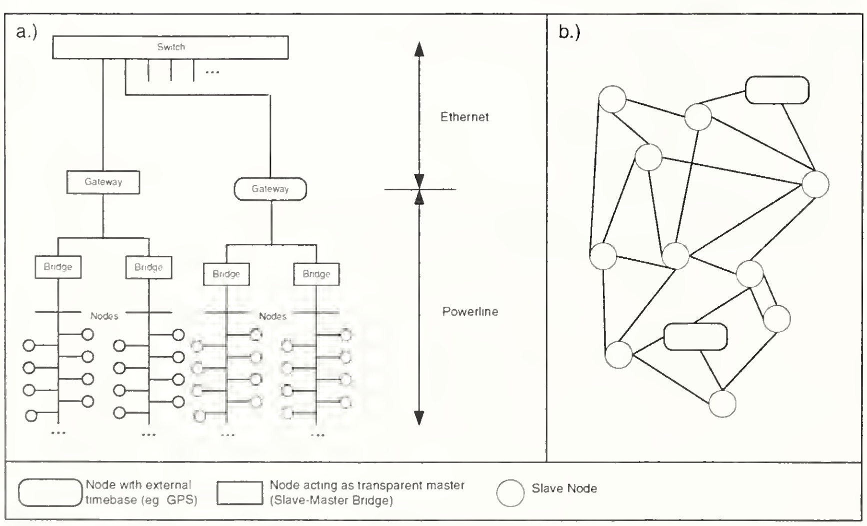
Synchronization in Distributed Systems

- Various approaches
  - NTP
  - IEEE1588
  - ***SynUTC***
- Different characteristics
  - Purely software based
  - Limited hard- and software resources
  - Fault tolerance and/or redundant signals paths
  - Clock architectures

Requirements for Control applications

- Basic Data
  - Achievable accuracy
  - Upper bound for inaccuracy
  - Network load overhead
- Advanced Questions for Time Sync
  - Time distribution over heterogeneous networks
    - Ethernet, Powerline, Fieldbus
  - Behavior under any network load condition
  - Start-up and transient response
  - Response to complex (multi node) error conditions
  - Influence of COTS/custom network components

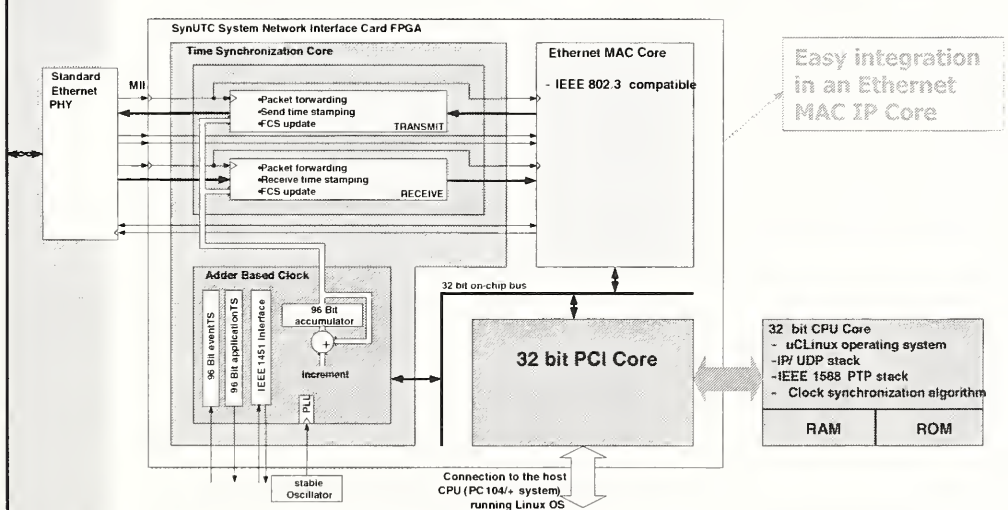
Time Synchronization Issues



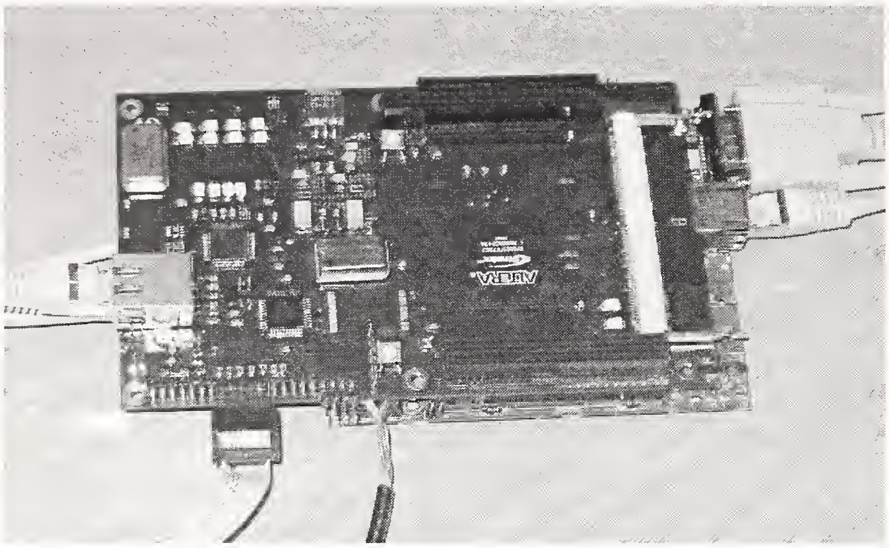
Synchronization Feature Analysis

- Theoretical (e.g. ***SynUTC***)
  - A set of "limiting" assumptions have to be made
  - Reliable results for
    - Steady state behavior
    - Worst case behavior
    - Response to single or well defined failures
- Measurement
  - Statistical data easily attainable
  - Internal state information
    - Clock and sync status
    - Sync packet loss and the like

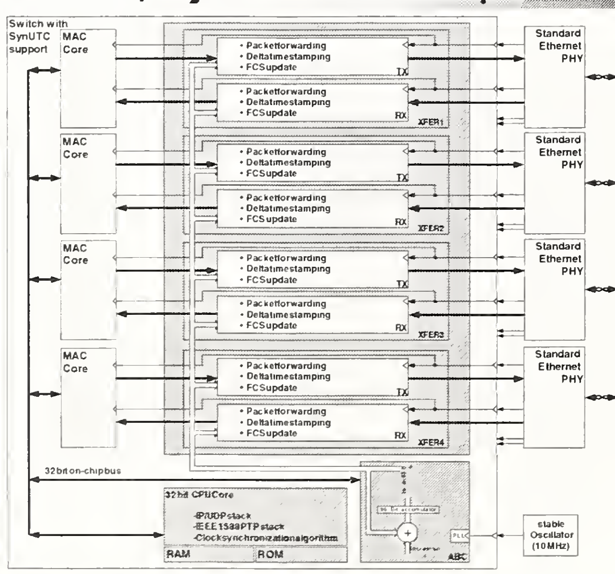
SynUTC Network Interface Card



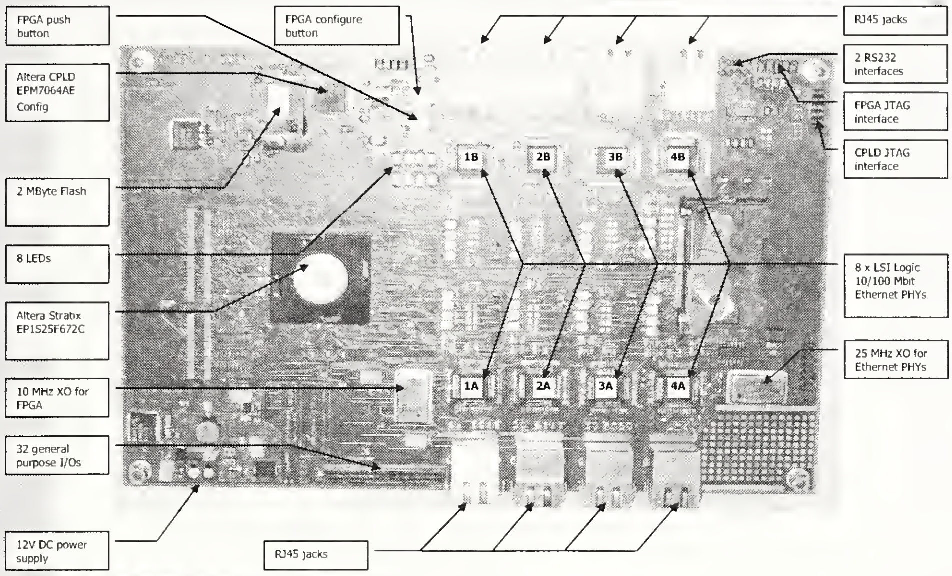
SynUTC Network Interface Card



IEEE1588/*SynUTC* Transparent Switch



IEEE1588/***SynUTC*** Transparent Switch



Synchronization Feature Analysis

- Limitations of measurement based analysis
  - Start-up behavior at any given boundary condition
  - Arbitrary start-up sequences
  - Transient response (to multi-node failures)
  - Varying load conditions
  - Varying accuracies and asymmetric delays
  - Fault tolerance
    - Best Master Group
    - Redundant signal paths
  - Heterogeneous networks
- Simulation does the trick

Network Simulation (I)

- Things to consider / model
  - Network topology description
- Model types for every node /module
  - Application layer
  - Software layer
    - protocol implementation and clock sync algorithms
  - Hardware link layer
    - Local clock timing and architecture
    - Digital clock domains and domain transitions
  - Physical layer
    - Latency and transmission delay jitter and skew

Network Simulation (II)

- Varying levels of abstraction
  - Software description
  - Dedicated clock and time stamping hardware
  - Network controller
- Different tools
  - SystemC / System Verilog
  - C/C++
  - VHDL /Verilog at RTL-Level
  - Network models (OMNET++)

Network Simulation (III)

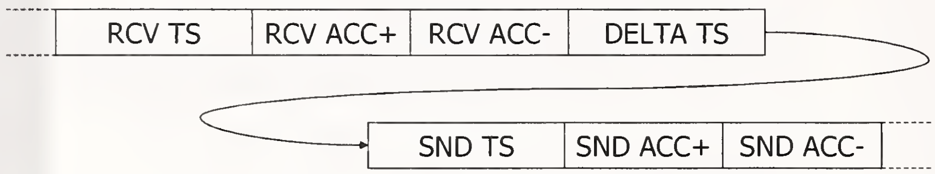
- Requirements for a simulation environment
  - Network topology description tools
  - Message passing mechanism
  - Foreign models and simulators linkable/attachable
    - C/C++
    - SystemC / System Verilog Library
    - Modelsim®
  - Sophisticated analysis tools
    - Graphical analysis
    - Log Files

Network Simulation (IV)

- OMNET++ chosen as simulation environment
  - Public domain for research
  - Open source (allows for attaching of simulators)
  - Models available on application layer
  - Graphical front end
  - Feature List
    - modeling discrete event systems.
    - traffic modeling of telecommunication networks
    - protocol modeling
    - modeling of queuing networks
    - modeling of distributed hardware systems

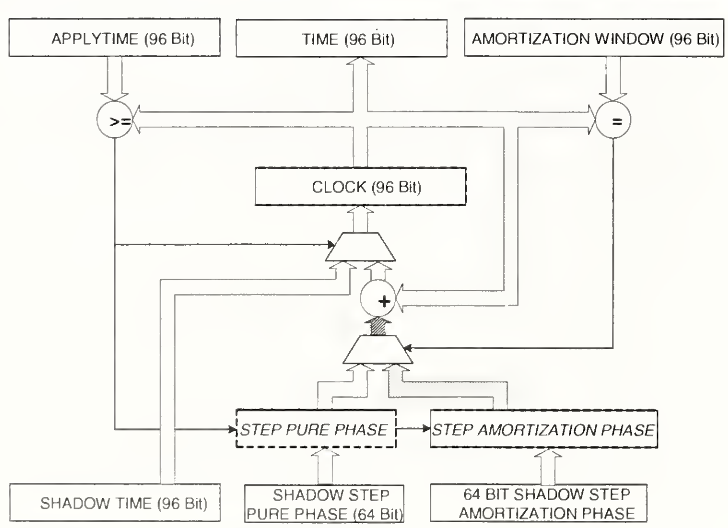
SynUTC On-the-Fly Timestamping

Sync and delay packets shall contain:



- Small additional hardware
- Much easier for software

SynUTC Adder Based Clock



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Implementation and Performance of Time Stamping Techniques

Prof. Hans Weibel and Dominic Béchaz,
Zurich University of Applied Sciences,
Winterthur, Switzerland

Contents

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1. Factors determining Sync Precision
2. The Test Platform
3. Hardware assisted Time Stamping
    - The test setup
    - Results
4. Software Time Stamping (NIC Driver)
    - The test setup
    - Results
    - Factors affecting time stamp accuracy
5. Conclusions

1. Factors determining Sync Precision

--- PTP Message Exchange

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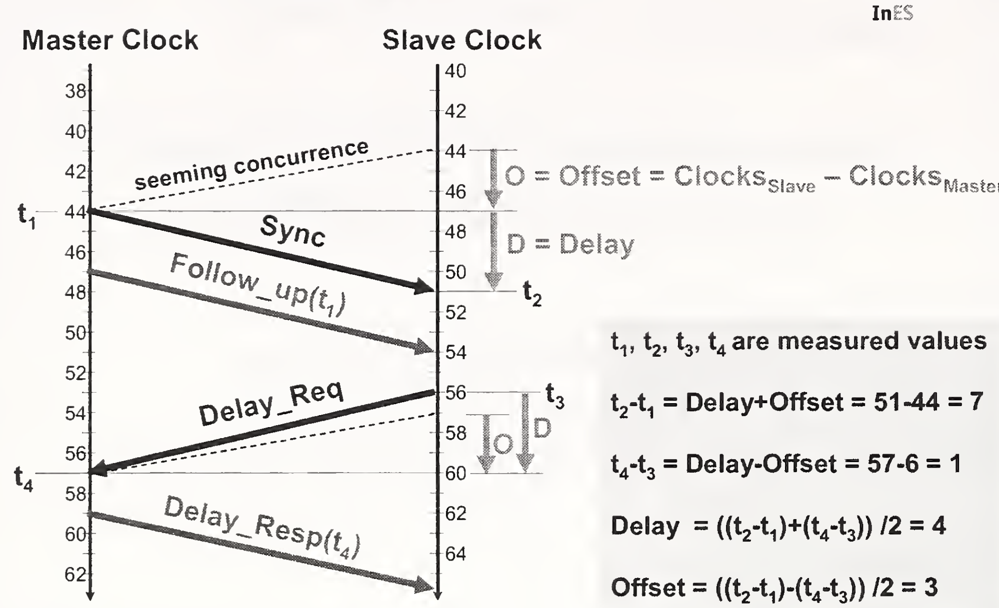

t_1, t_2, t_3, t_4 are measured values

$t_2 - t_1$ = Delay+Offset = 51-44 = 7

$t_4 - t_3$ = Delay-Offset = 57-6 = 1

Delay = $((t_2-t_1)+(t_4-t_3))$ /2 = 4

Offset = $((t_2-t_1)-(t_4-t_3))$ /2 = 3

1. Factors determining Sync Precision

--- PTP's Performance

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Performance depends on ...

- the communication channel's symmetry (i.e. same delay in both directions and constant over a longer period of time)
- drift compensated clocks (i.e. same time base in master and slave clocks)
- time stamp accuracy
- time stamp resolution
- sync interval
- clock stability
- clock control loop characteristics

1. Factors determining Sync Precision

--- PTP's operational Environment

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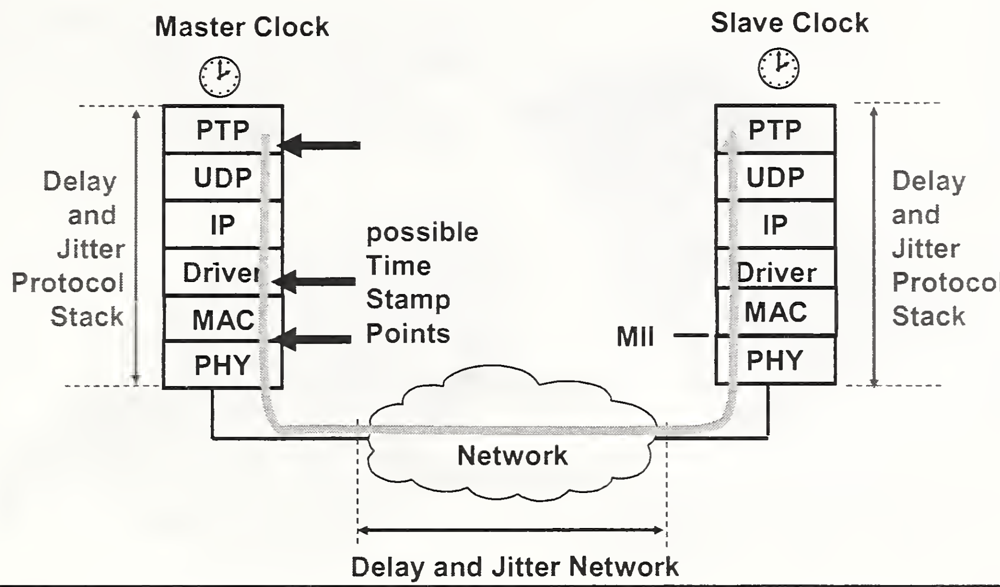

2. The Test Platform

--- The Evaluation Kit

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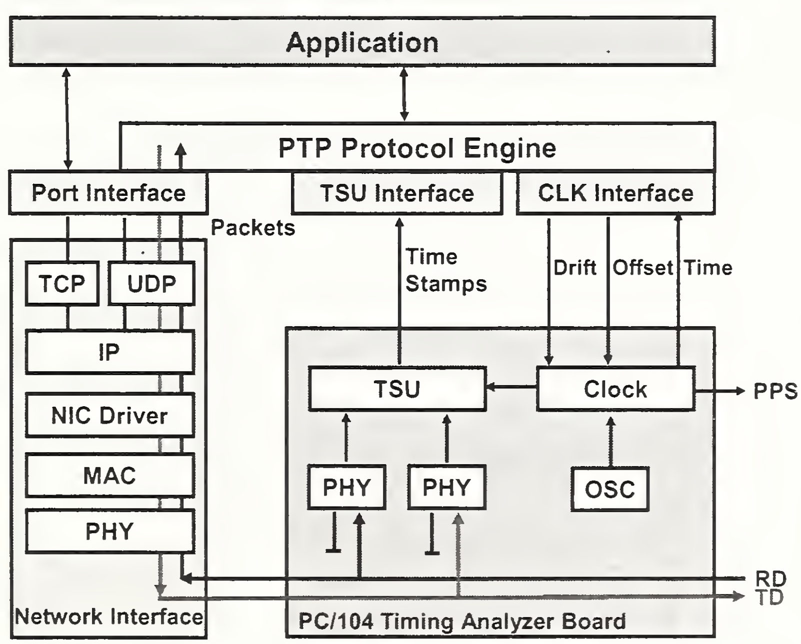

2. The Test Platform

--- The Evaluation Kit (cont'd)

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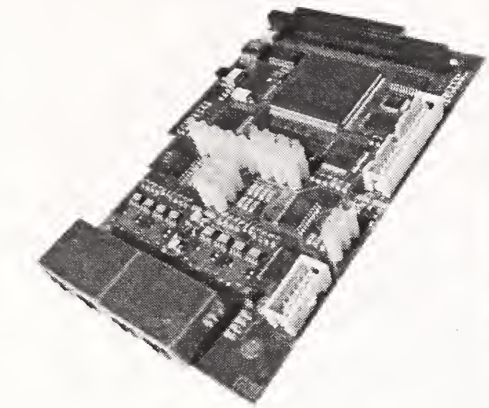
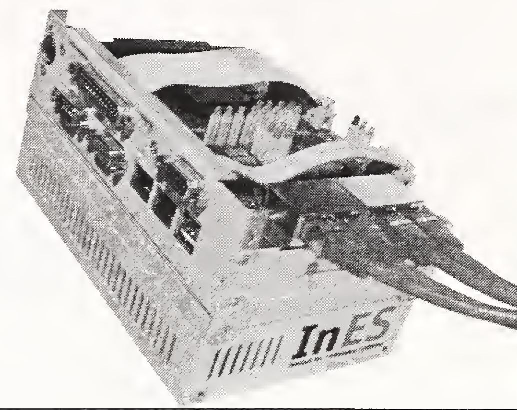
Industrial PC: CPU Geode 300MHz
OS: Gentoo Linux
kernel = vanilla 2.4.27
PTP Protocol Engine:
Hirschmann Electronics





Timing Analyzer Board:
Hardware clock and time stamping unit (time stamp resolution 20ns)

3. Hardware assisted Time Stamping

--- Time Stamping Points

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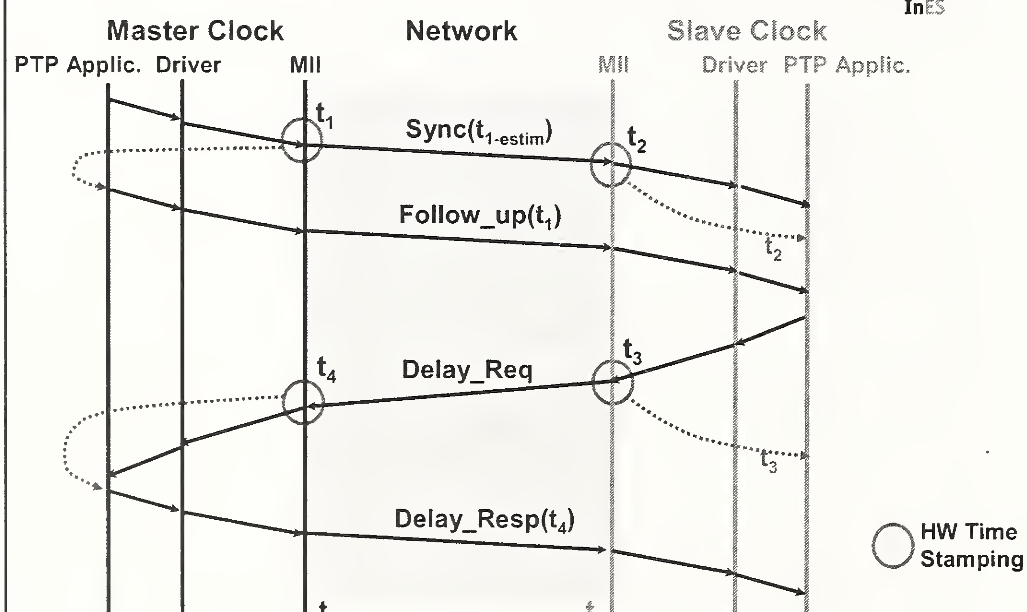

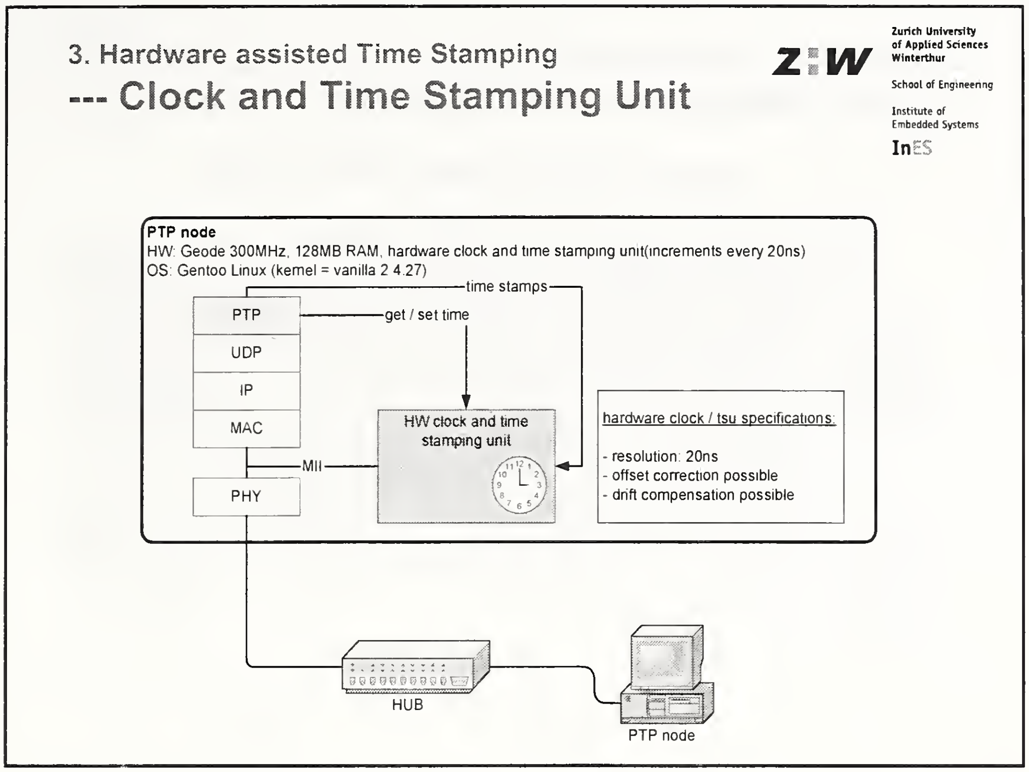
3. Hardware assisted Time Stamping
--- Clock and Time Stamping Unit
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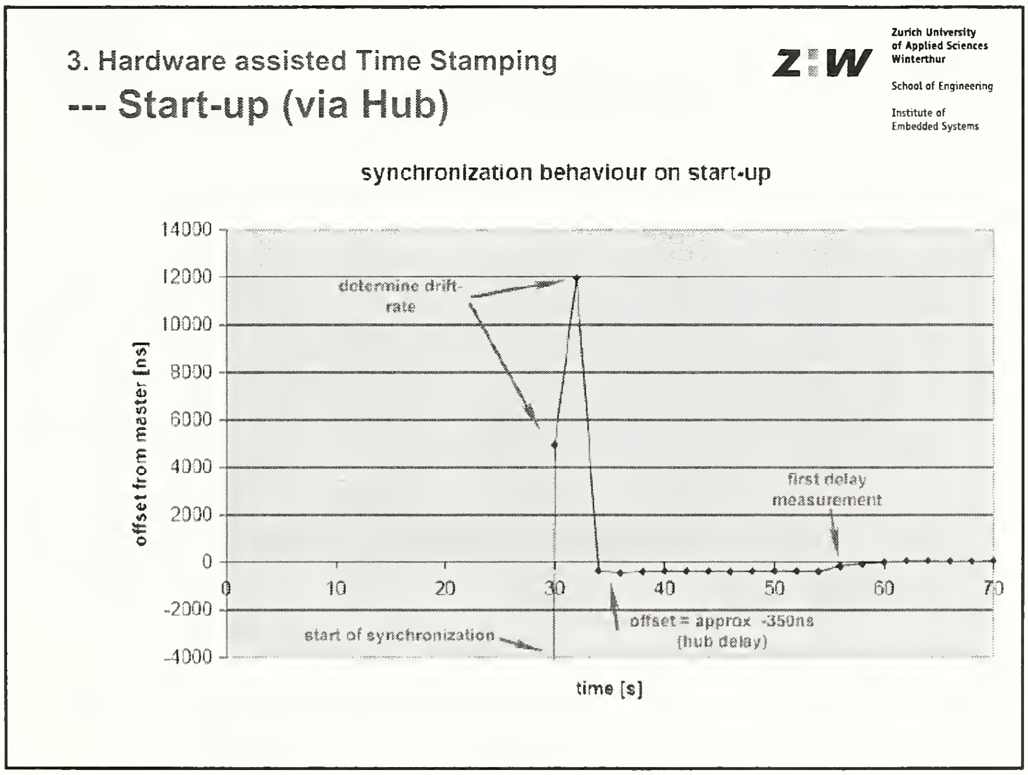
InES
PTP node
HW: Geode 300MHz, 128MB RAM, hardware clock and time stamping unit(increments every 20ns)
OS: Gentoo Linux (kernel = vanilla 2.4.27)
time stamps
PTP
get / set time
UDP
IP
MAC
HW clock and time stamping unit
hardware clock / tsu specifications:
- resolution: 20ns
- offset correction possible
- drift compensation possible
MII
PHY
HUB
PTP node


3. Hardware assisted Time Stamping
--- Start-up (via Hub)
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synchronization behaviour on start-up
determine drift-rate
first delay measurement
offset = approx. -350ns (hub delay)
start of synchronization
offset from master [ns]
time [s]

3. Hardware assisted Time Stamping

--- Synchronization (via Hub)

Z W

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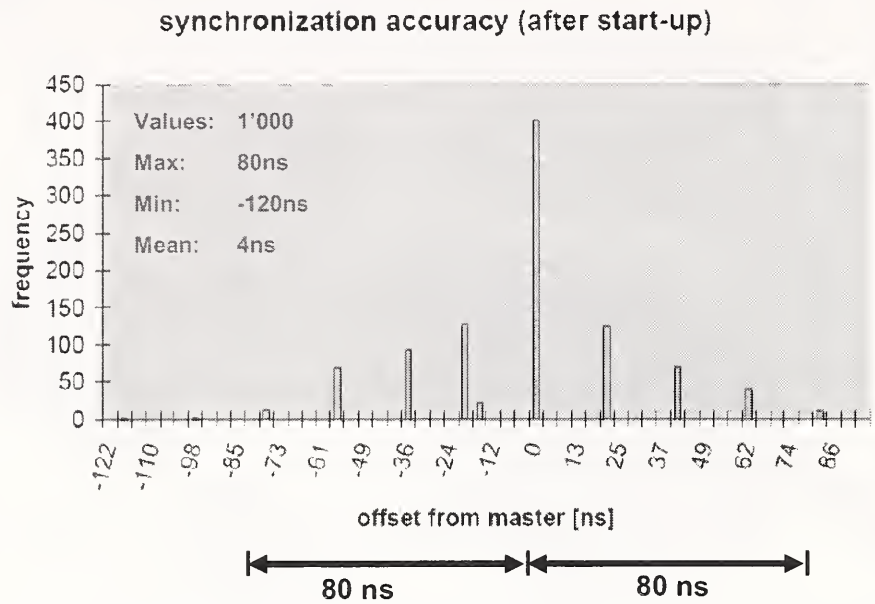

3. Hardware assisted Time Stamping

--- Synchronization (via Switch, no Load)

Z W

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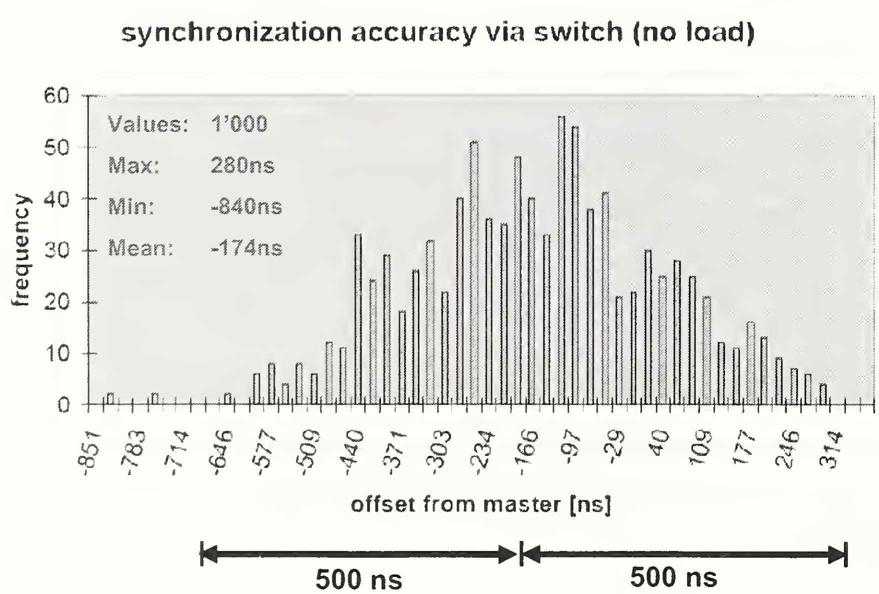

3. Hardware assisted Time Stamping

--- Network Setup: Switch under Load

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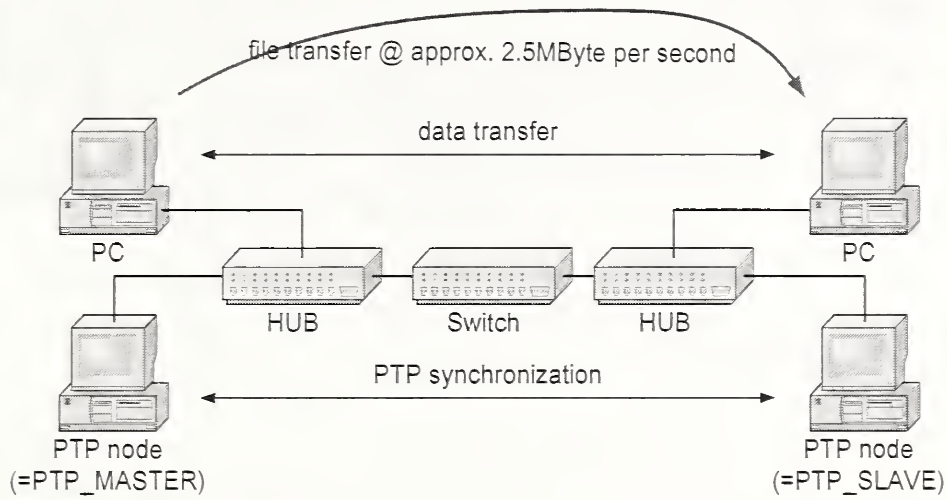

3. Hardware assisted Time Stamping

--- Synchronization (via Switch, with Load)

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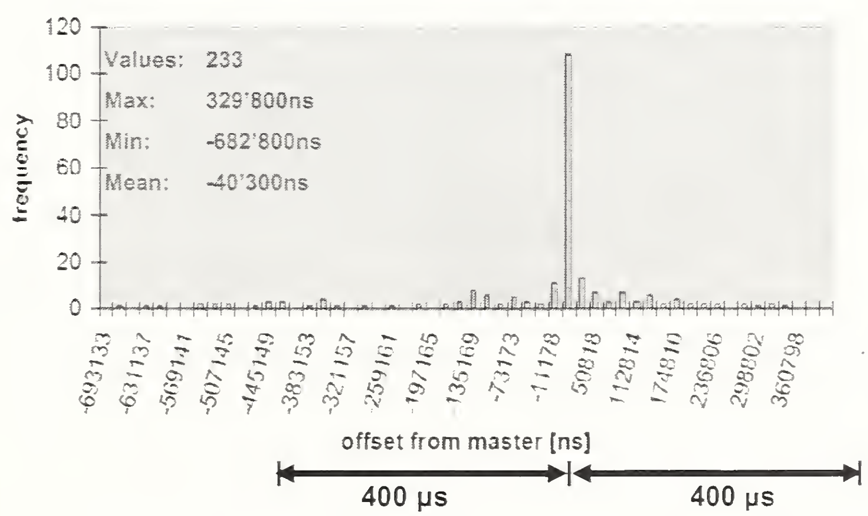
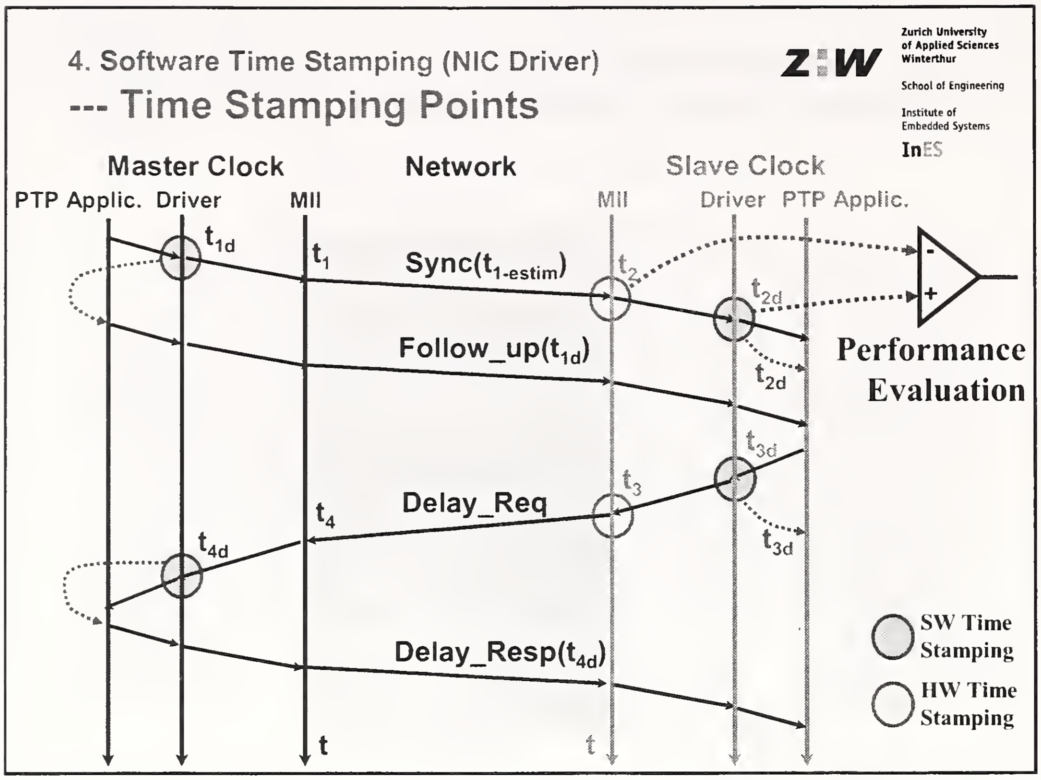
synchronization accuracy via switch (+load)




4. Software Time Stamping (NIC Driver)
--- Time Stamping Points
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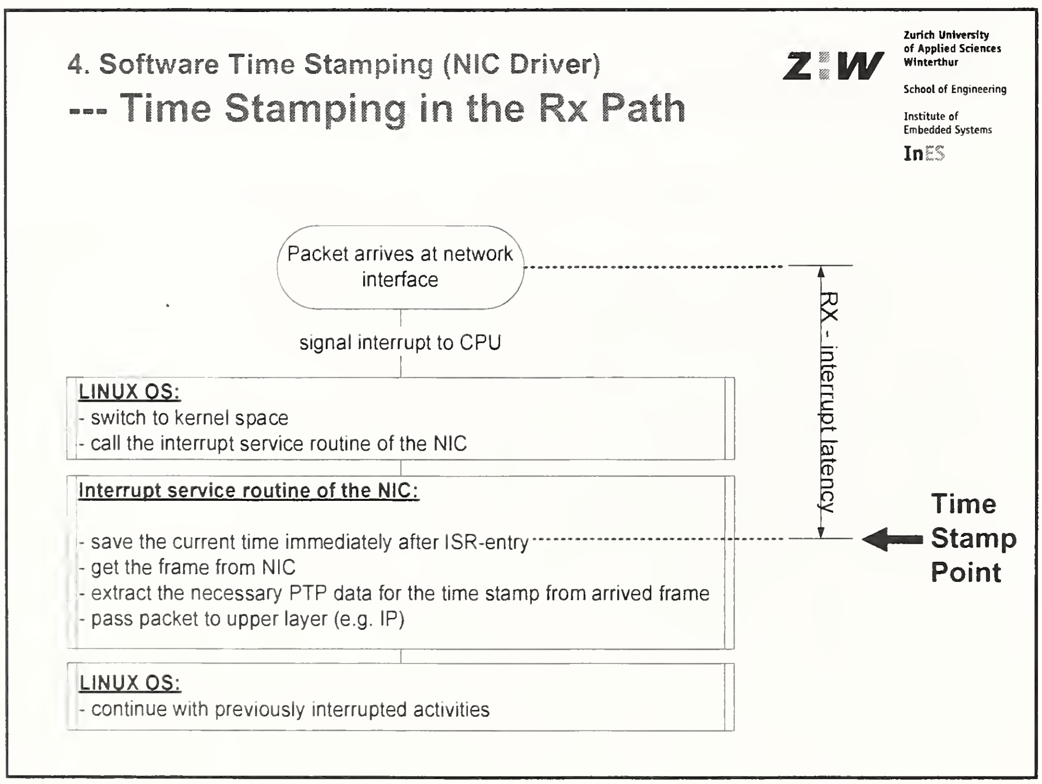
Master Clock
Network
Slave Clock
PTP Applic.
Driver
MII
MII
Driver
PTP Applic.
t1d
t1
Sync(t1-estim)
t2
t2d
t2d
Follow_up(t1d)
Performance Evaluation
t3d
t3
Delay_Req
t4
t4d
t3d
Delay_Resp(t4d)
SW Time Stamping
HW Time Stamping
t
t


4. Software Time Stamping (NIC Driver)
--- Time Stamping in the Rx Path
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Packet arrives at network interface
signal interrupt to CPU
LINUX OS:
- switch to kernel space
- call the interrupt service routine of the NIC
Interrupt service routine of the NIC:
- save the current time immediately after ISR-entry
- get the frame from NIC
- extract the necessary PTP data for the time stamp from arrived frame
- pass packet to upper layer (e.g. IP)
LINUX OS:
- continue with previously interrupted activities
RX - interrupt latency
Time Stamp Point

4. Software Time Stamping (NIC Driver)
--- Time Stamping in the Tx Path

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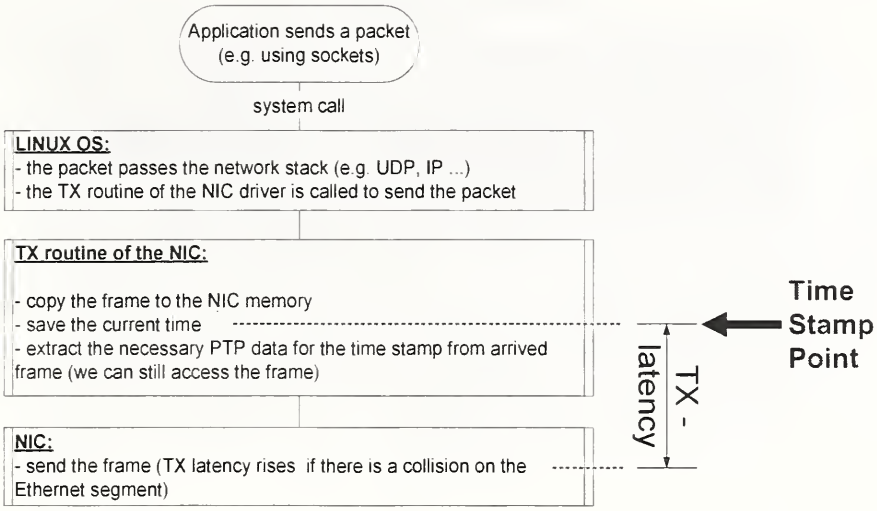

4. Software Time Stamping (NIC Driver)
--- Measurement Setup

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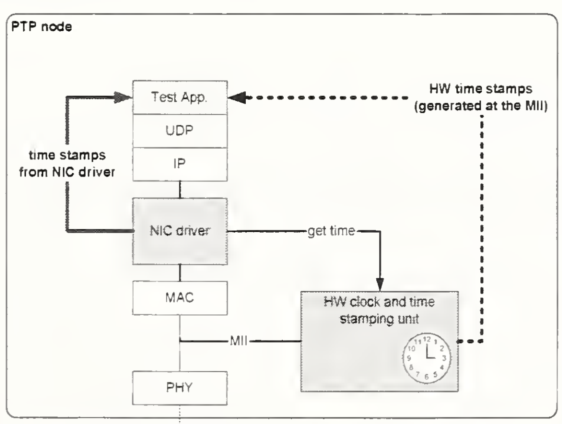

incoming packets:
RX latency = (NIC driver time stamp) - (HW time stamp)

outgoing packets:
TX latency = (HW time stamp) - (NIC driver time stamp)

4. Software Time Stamping (NIC Driver)
--- Rx Latency

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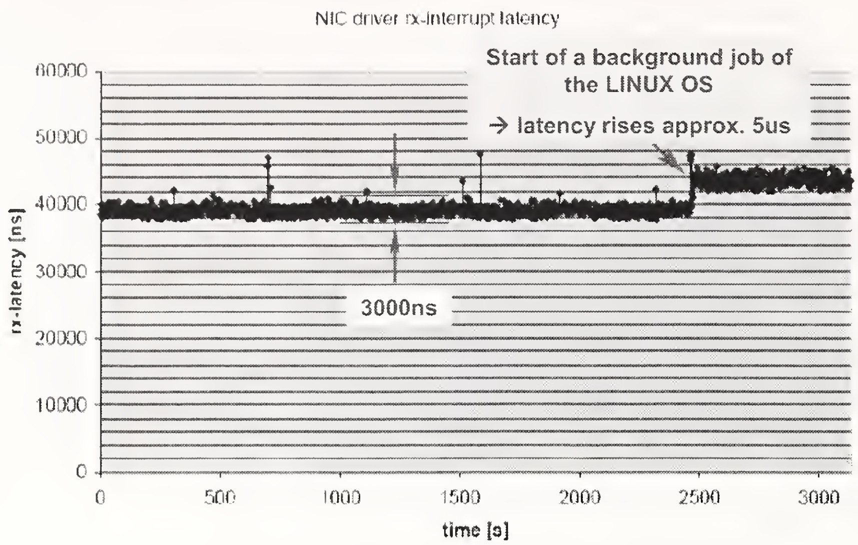

4. Software Time Stamping (NIC Driver)
--- Tx Latency

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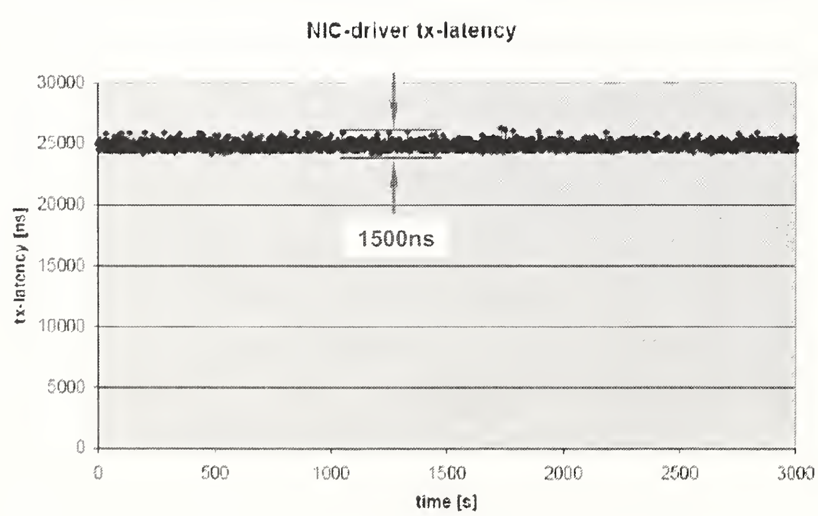
Institute of Embedded Systems
InES



4. Software Time Stamping (NIC Driver)
--- Setup: Hub, PTP_Slave under Load

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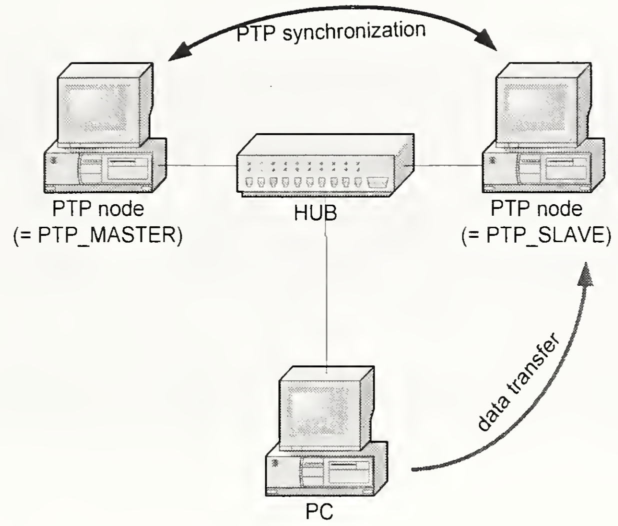

4. Software Time Stamping (NIC Driver)
--- Rx Latency (Node under Load)

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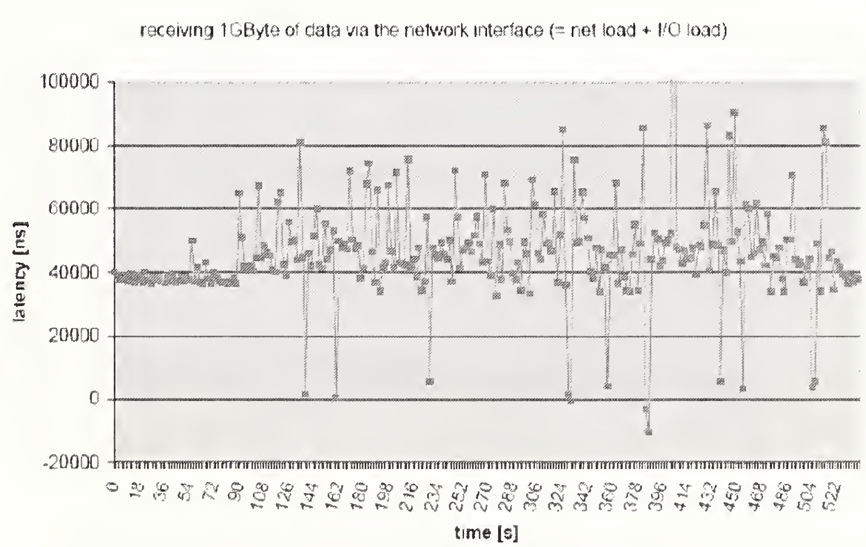

4. Software Time Stamping (NIC Driver)

--- Tx Latency (Node under Load)

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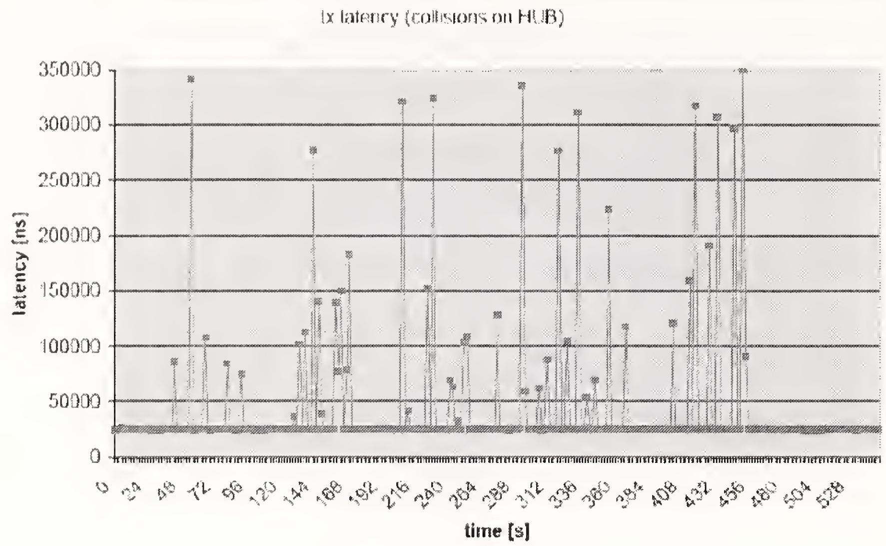

4. Software Time Stamping (NIC Driver)

--- Synchronization: Hub, no Load

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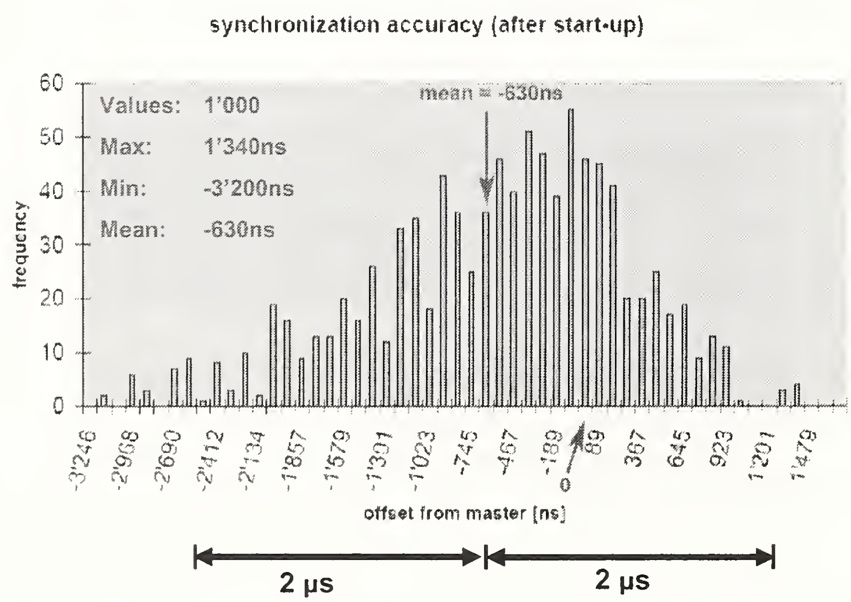

4. Software Time Stamping (NIC Driver)
--- Setup: asymmetric Configuration

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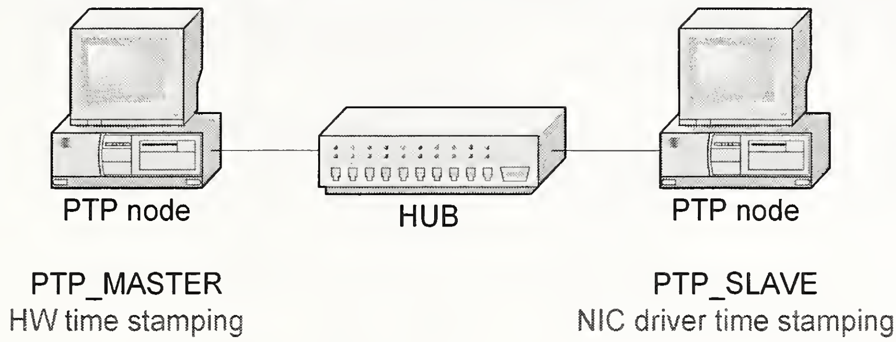

4. Software Time Stamping (NIC Driver)
--- Synchronization (no Load)

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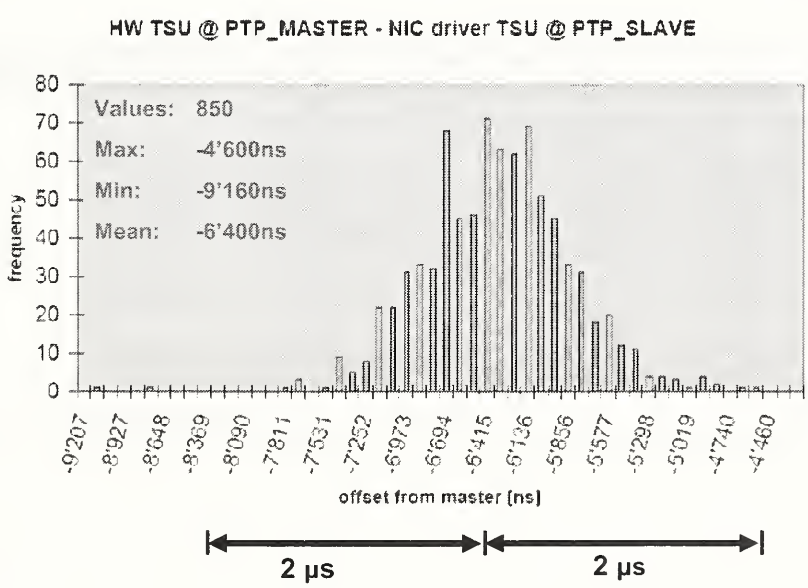

5. Conclusions
--- Lessons learned

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How to reach better SW timestamp accuracy

Action	Result
Use fast (i.e. good performance in general) PTP nodes.	The better the performance of the node, the lower the ISR latency and its jitter.
Do not allow long period disk I/O (and other load that raises ISR latency) on the PTP nodes.	Peaks in ISR latency can be detected and filtered out if they don't happen over a long period of time.
Do not allow long periods of high network load on the Ethernet segment.	Less collisions result in less Tx latency peaks. Less Rx latency peaks at incoming traffic.

5. Conclusions
--- Lessons learned (cont'd)

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How to reach better SW timestamp accuracy

Action	Result
Detect ISR latency peaks and bypass adjustment control for the clock if a peak happens.	No leaps in time. But if peaks occur successively over a long period of time, the clock may drift away.
If the interrupt latency of the nodes are known, path asymmetry can be included in the offset calculation.	No constant offset from master due to path asymmetry. → Only possible in a fix environment (each node knows its own Rx / Tx latency).

5. Conclusions

--- Summary

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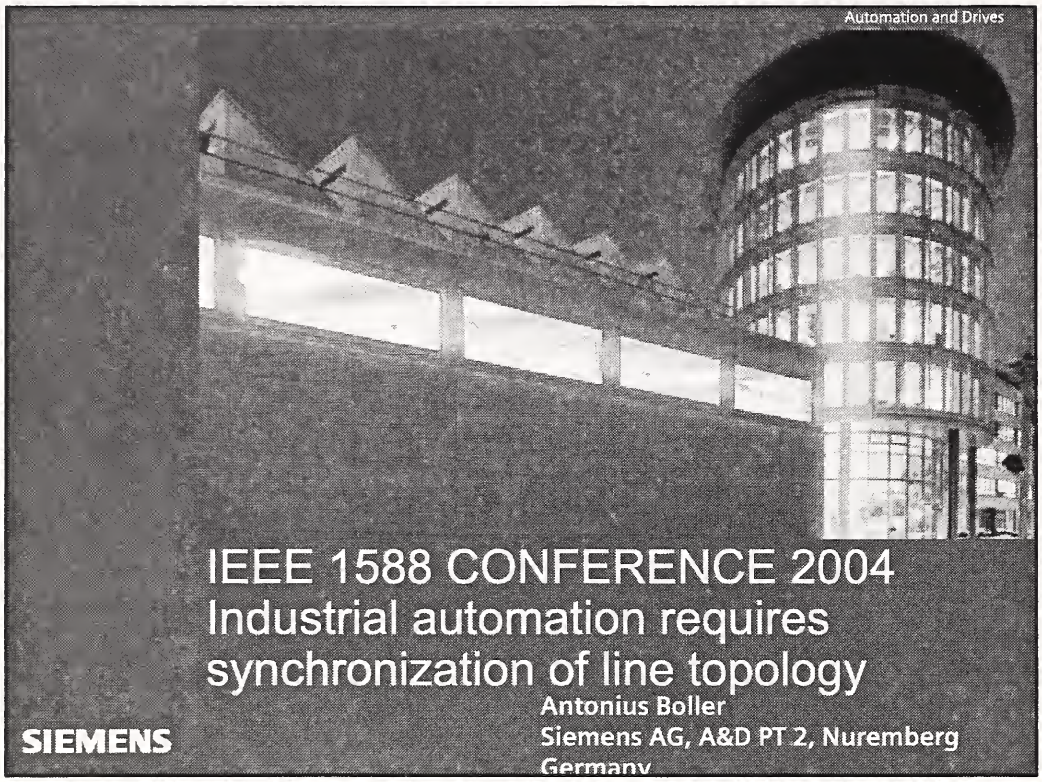
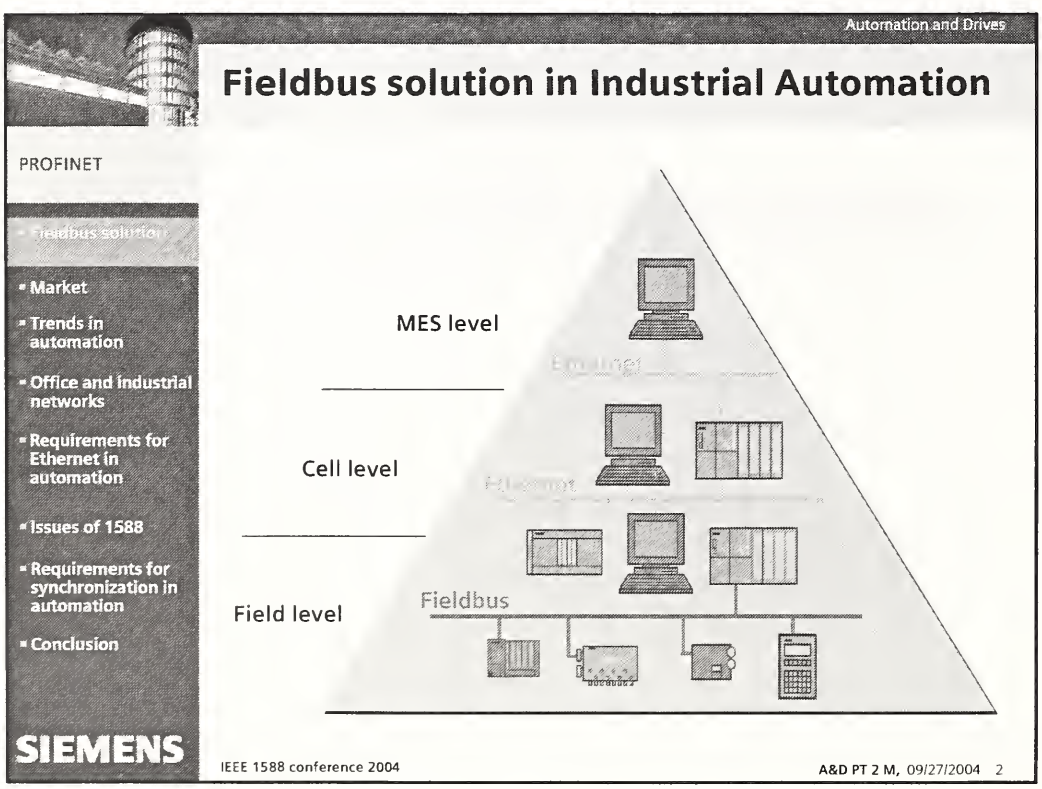
Time stamp accuracy degradation is caused by

- System load (especially I/O)
  → Rx latency rises
- Network traffic destined to a PTP node
  → Rx latency rises
- Network traffic on the Ethernet segment
  → Tx latency rises due to collisions
- Computing performance in general

SW time stamp accuracy highly depends on the PTP node's SW environment and on the network structure and traffic pattern.


Automation and Drives
IEEE 1588 CONFERENCE 2004
Industrial automation requires
synchronization of line topology
Antonius Boller
Siemens AG, A&D PT 2, Nuremberg
Germany
SIEMENS


Automation and Drives
Fieldbus solution in Industrial Automation
PROFINET
Market
Trends in automation
Office and industrial networks
Requirements for Ethernet in automation
Issues of 1588
Requirements for synchronization in automation
Conclusion
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MES level
Cell level
Field level
Fieldbus
IEEE 1588 conference 2004
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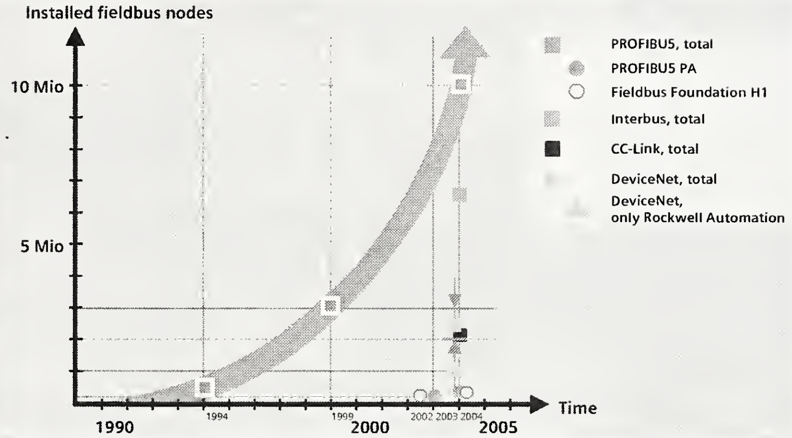
Automation and Drives

Installed fieldbus nodes

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion



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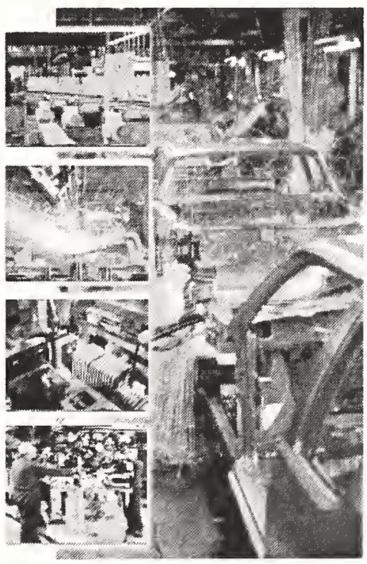
Automation and Drives

Technological trends in automation

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

- Trend away from central control structures to distributed local units
- Use of Ethernet at all levels of automation
- Increase in use of open IT standards in automation
- IT- and automation world are growing together



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Results of market surveys

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

ARC Advisory Group (2003)
Annual growth rate (2002-2007)
of 90% for Ethernet field devices

Frost & Sullivan (2002)
Market share of Ethernet in the fieldbus market
2001: < 2,5% → 2006: 14,2%

VDC, (Second Edition 2001)
Market share of Ethernet field devices
2000: 11,1% → 2006: 26,4%

Conclusion of all market surveys:

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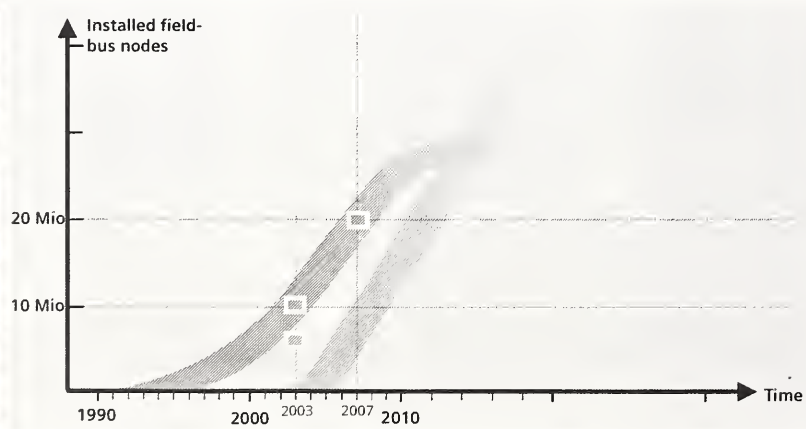
PROFIBUS and PROFINET (Ethernet)

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion



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Automation and Drives

Benefits of Ethernet in an industrial environment

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

A uniform network structure

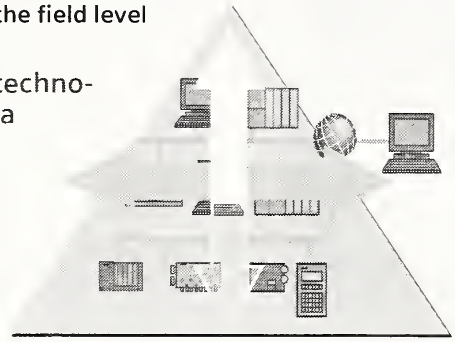
- Reduce the interfaces
- Plant wide Engineering
- Continuity through to the field level

Use the advantages of IT-technology in the production area

- Remote Access
- Web services
- Software updates

Improvements relative to today's systems

- High performance
- Unlimited quantities
- Simple Handling



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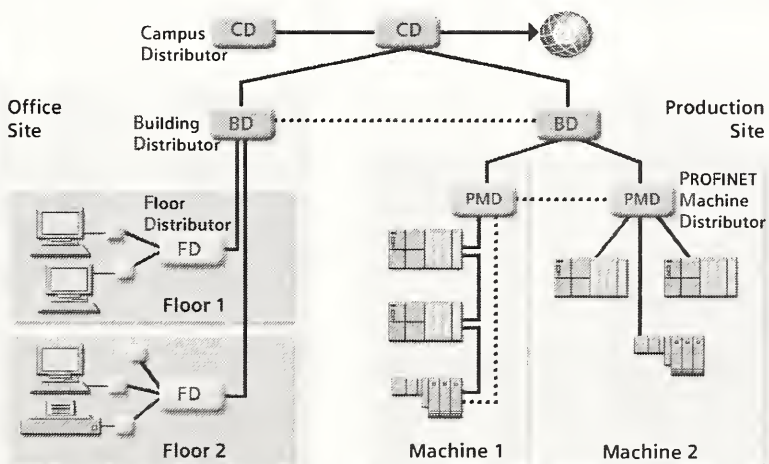
Automation and Drives

Differences between office and industrial networks

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion



- Fixed basic installation combined with variable device interface
- Star and tree structures

- Plant-specific cable routing with individual networking structure
- Star, ring and linear structures

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Automation and Drives

Differences between office and industrial networks

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

Office	Industry
Fixed basic installation in buildings	Extreme plant specific cabling routing
Separate floor distribution boxes	Plant specific cabling routing
Variable connection of devices	Connection points are rarely changed
Pre-assembled connection cables	Assembly of the connections in the field
Tree network structure	Often line structures and/ or (redundant) ring structures
Big data packages (e.g. pictures)	Small data packages (process values)
Average requirements of availability	Extremely high requirements
Moderate temperatures (from 0 to 50°C)	Extreme temperatures (from -20 to +70°C)
No moisture	Moisture possible (IP65)
No vibration loads	Vibrating machines
Low EMC load	High EMC load
Insignificant mechanical danger	Danger of mechanical damaging
Insignificant chemical danger	Danger of chemical damaging due to oil and aggressive environments

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Automation and Drives

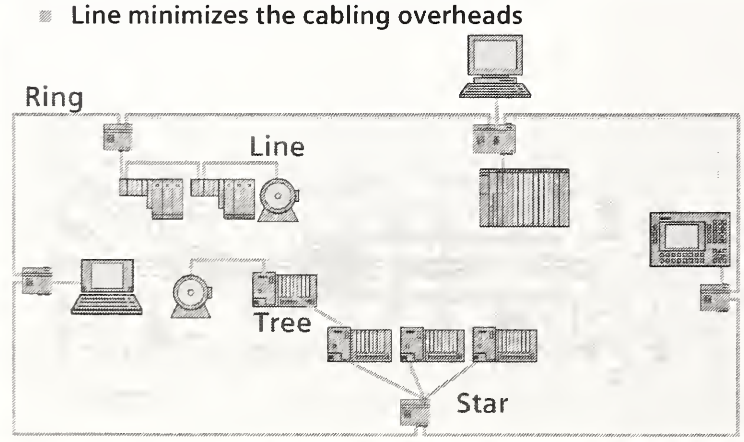
Industrial Ethernet - topologies

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

All topologies can be used

- Ring structure guarantees high availability
- Line minimizes the cabling overheads



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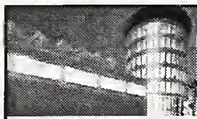

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Requirements for Ethernet in Automation

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

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Topology
- All network topologies possible (star,tree, line, ring)
- Redundancy

IT and Standard Functionality
- Open for TCP/IP and IT applications
- Unlimited network access for any devices

Real-Time
- Real-time features for motion control
- Maintain real-time features under any network situation
- Interrupt-free redundancy

Technology
- Use of future oriented switching technology

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Automation and Drives

Benefits of Switching Technology

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

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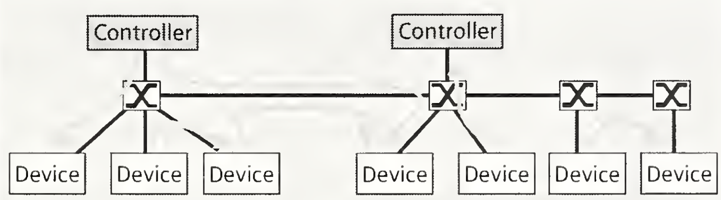
Reason for use of end-to-end switching technology
- State of the art in the world of communication
- Prospects for further development
- Prevent collisions
- Transmit full duplex, parallel data exchange
- Quality of service (prioritizing real-time messages)
- Switch integration in the device
  - Simplify installation of devices
  - Minimizes the cabling



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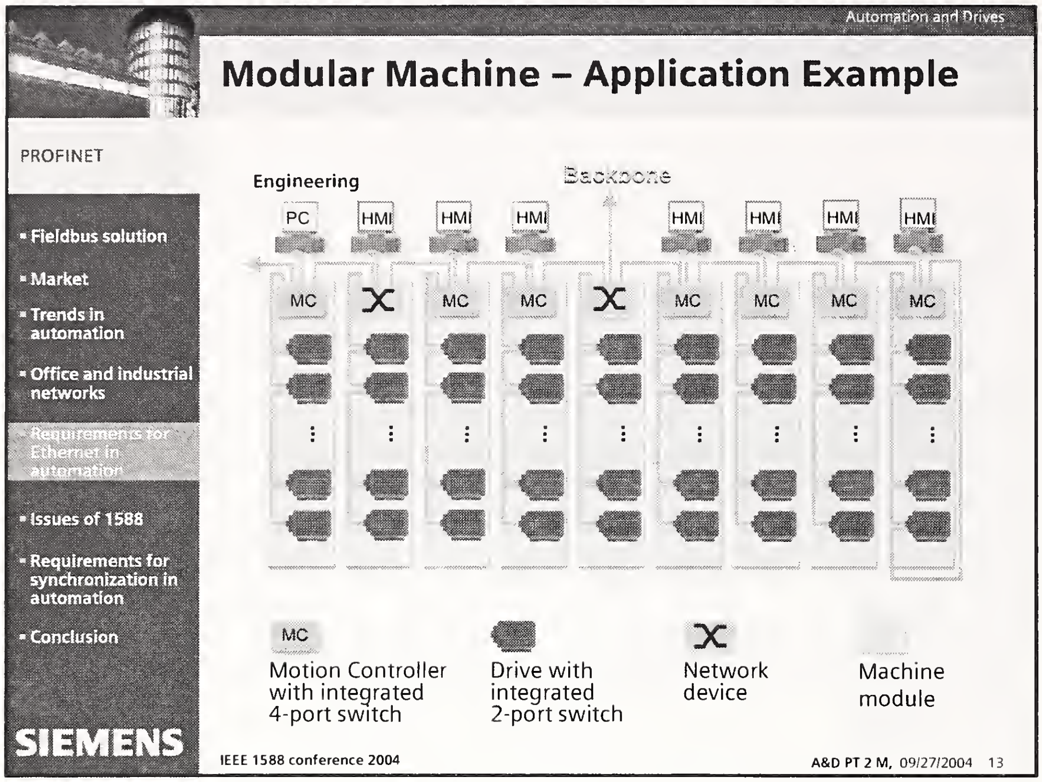
Automation and Drives
Modular Machine – Application Example
PROFINET
▪ Fieldbus solution
▪ Market
▪ Trends in automation
▪ Office and industrial networks
Requirements for Ethernet in automation
▪ Issues of 1588
▪ Requirements for synchronization in automation
▪ Conclusion
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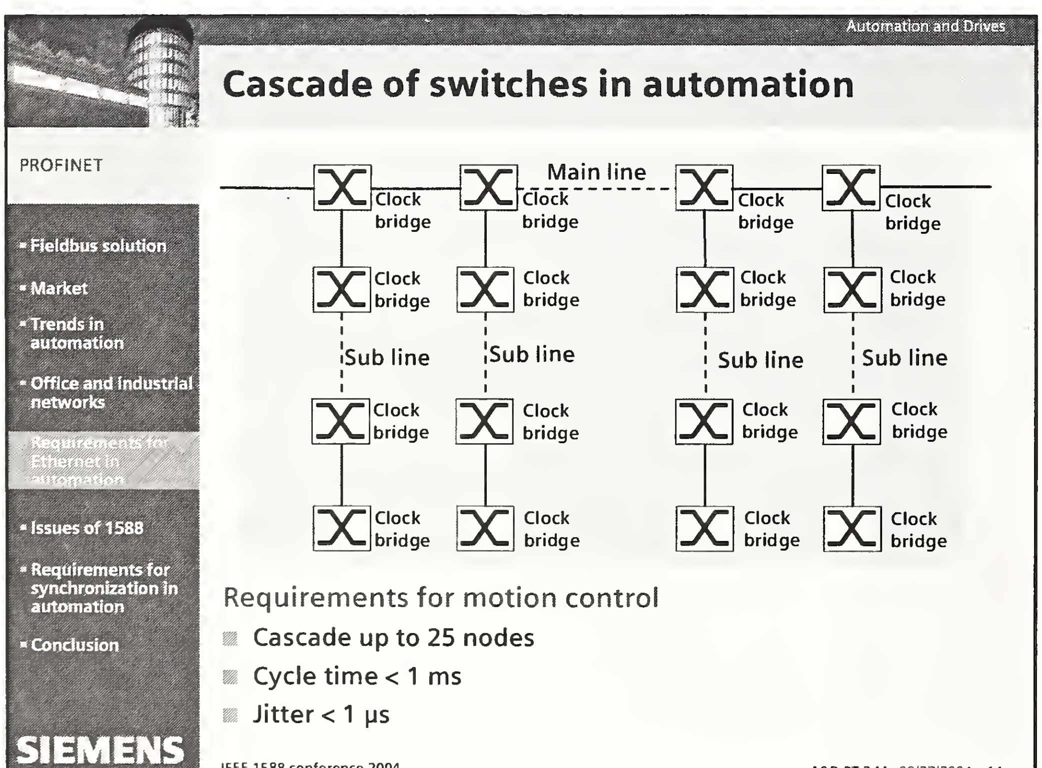
Engineering
Backbone
PC
HMI
MC
MC
Motion Controller with integrated 4-port switch
Drive with integrated 2-port switch
Network device
Machine module
IEEE 1588 conference 2004
A&D PT 2 M, 09/27/2004 13


Automation and Drives
Cascade of switches in automation
PROFINET
▪ Fieldbus solution
▪ Market
▪ Trends in automation
▪ Office and industrial networks
Requirements for Ethernet in automation
▪ Issues of 1588
▪ Requirements for synchronization in automation
▪ Conclusion
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Main line
Clock bridge
Sub line
Requirements for motion control
Cascade up to 25 nodes
Cycle time < 1 ms
Jitter < 1 µs
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Issues of 1588

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

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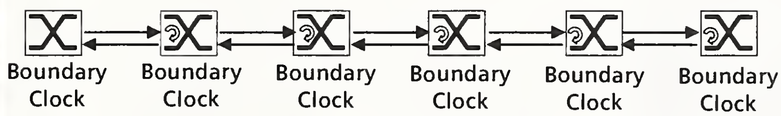
1588 method for switches in a line

- Cascade of Boundary Clocks (Switches)
- Series connection of control loops
- Synchronization frequency in seconds
- Jitter accuracy > 1 μs for cascaded switches (with COTS. oscillator)
- Start up time up to several minutes
- Boundary Clock (Switch) needs extensive software



Synchronization requirements

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

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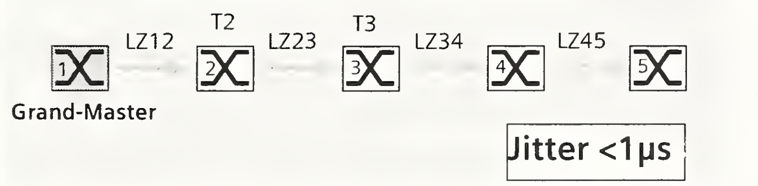
Requirements for synchronization in automation

- Simple and fast method
- Robust and stable
- Easy and cheap software implementation for every device
- Possibility for hardware implementation
- Jitter accuracy < 1 μs for line topology
- Permanent operation of active components
- Redundancy aspects



Tx: Transfer time through switch x

LZxy: propagation time between switch x and switch y

Automation and Drives

Compatibility with 1588

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

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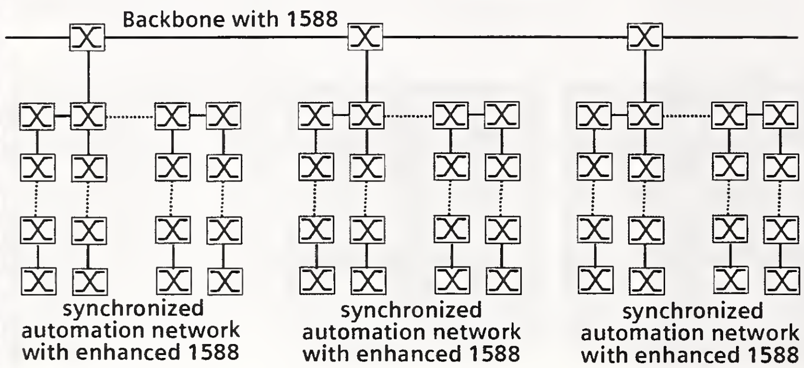
Requirements for compatibility

- Compatible with 1588
- Transparent for 1588
- Seamless clock synchronization



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Automation and Drives

Conclusion

PROFINET

- Fieldbus solution
- Market
- Trends in automation
- Office and industrial networks
- Requirements for Ethernet in automation
- Issues of 1588
- Requirements for synchronization in automation
- Conclusion

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Requirements in automation

- All network topologies (star,tree, line, ring)
- Use of future oriented switching technology
- Switch integration in the device
- Real-time features for motion control
- Interrupt-free redundancy
- Easy and cheap implementation

Potential of 1588

- 1588 is a standard with high potential for automation
- Solution for precise synchronization of line topology required
- Consideration of devices with integrated switch are required

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1

IEEE 1588 Ethernet Switch Transparency

-

No need for Boundary Clocks!

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Øyvind Holmeide
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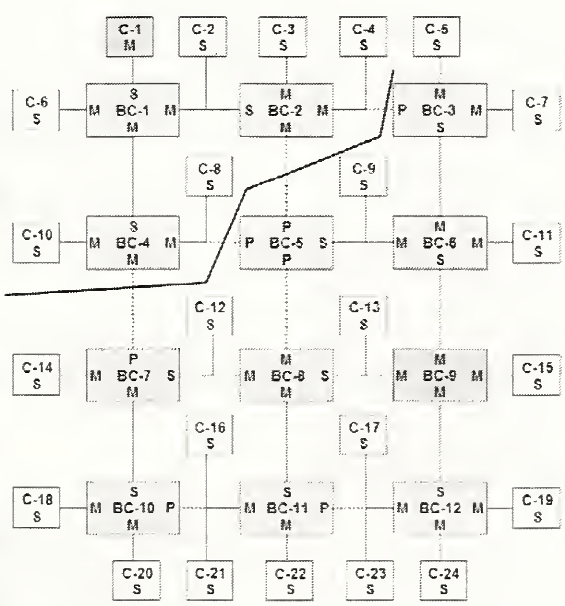
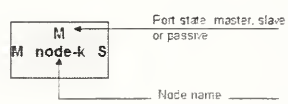
OnTime networks

2

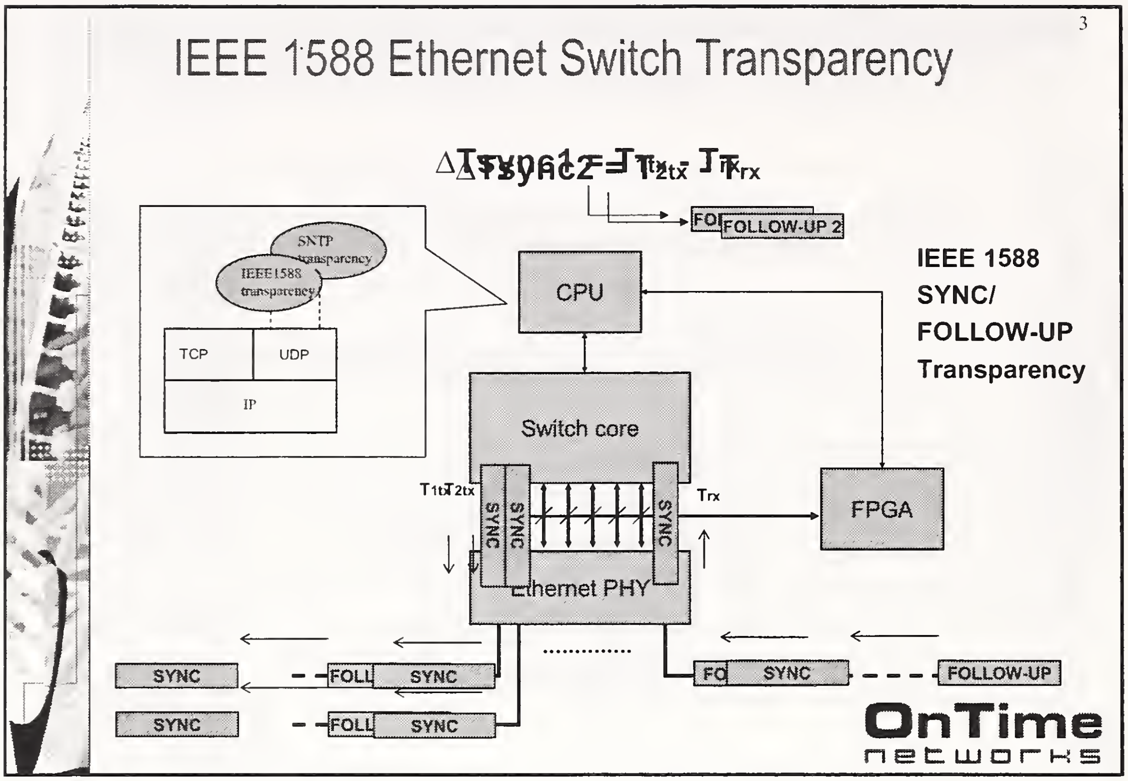
IEEE 1588 Ethernet Switch Transparency

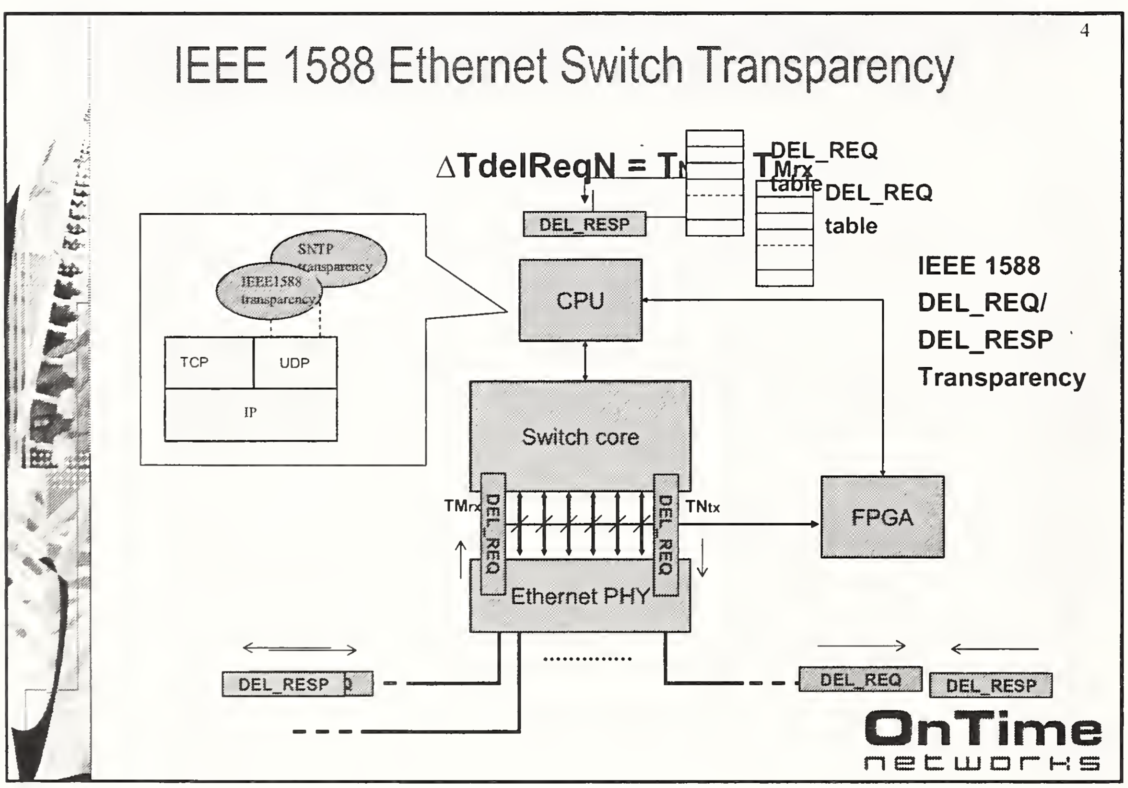


Network with Boundary Clocks

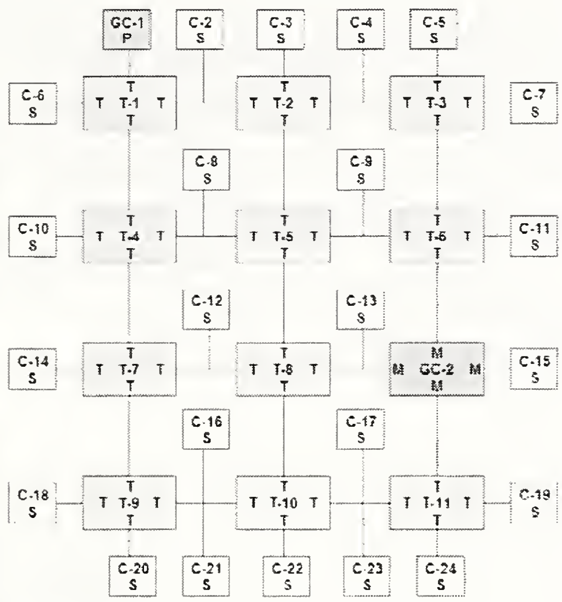


OnTime networks

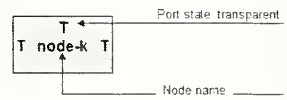

3
IEEE 1588 Ethernet Switch Transparency
FOLLOW-UP 2
IEEE 1588
SYNC/
FOLLOW-UP
Transparency
SNTP transparency
IEEE1588 transparency
TCP
UDP
IP
CPU
Switch core
Trx
FPGA
SYNC
SYNC
SYNC
Ethernet PHY
SYNC
SYNC
SYNC
FOLLOW-UP
SYNC
SYNC
OnTime networks


4
IEEE 1588 Ethernet Switch Transparency
DEL_REQ
DEL_REQ
table
DEL_RESP
IEEE 1588
DEL_REQ/
DEL_RESP
Transparency
SNTP transparency
IEEE1588 transparency
TCP
UDP
IP
CPU
Switch core
TMrx
TNtx
FPGA
DEL_REQ
DEL_REQ
Ethernet PHY
DEL_RESP
DEL_REQ
DEL_RESP
OnTime networks

IEEE 1588 Ethernet Switch Transparency

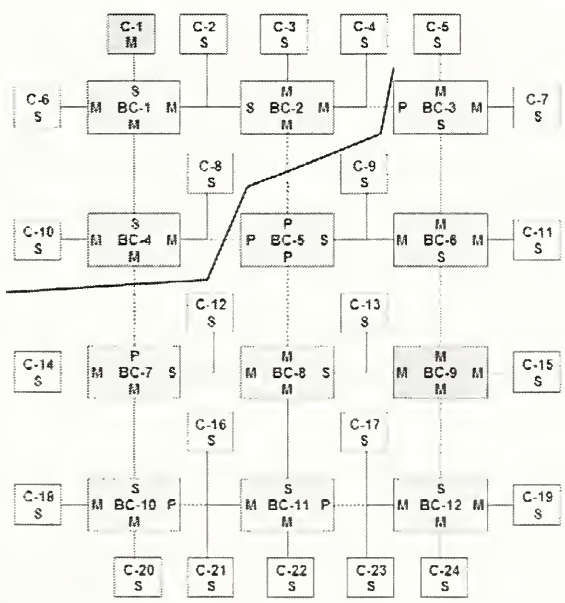


Network with Ethernet Switches IEEE1588 Transparency support

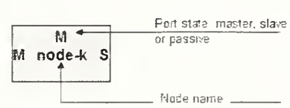


OnTime networks

IEEE 1588 Ethernet Switch Transparency



Network with Boundary Clocks



OnTime networks

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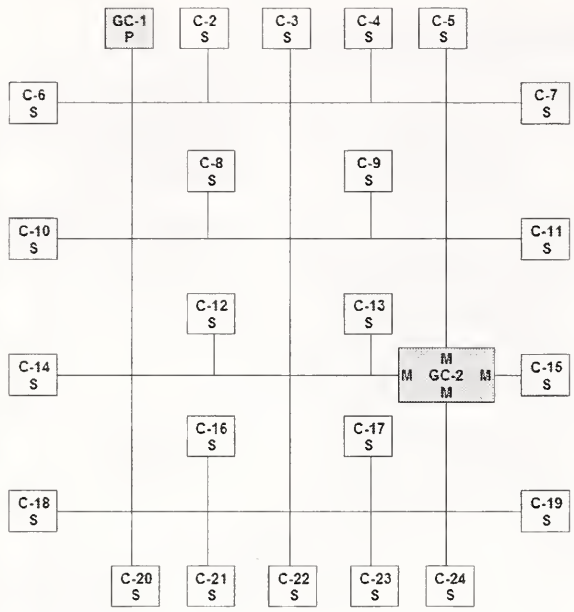
IEEE 1588 Ethernet Switch Transparency



IEEE1588 Transparency means one IEEE1588 network segment

8

IEEE 1588 Ethernet Switch Transparency

Impact on accuracy:

1. No synchronization of local Transparency clock
   Example:
   - ΔTsync ~1 ms
   - Local clock: 200 PPM
   - Error = 200 nS

9

IEEE 1588 Ethernet Switch Transparency

Impact on accuracy cont'd:

2. Synchronization of local Transparency clock based on incoming SYNC and FOLLOW_UP packets
   - Accuracy as for a corresponding Boundary clock
   - Only drift calculation

OnTime networks

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IEEE 1588 Ethernet Switch Transparency

Impact on accuracy cont'd:

3. Synchronization of local Transparency clock based IEEE1588 Slave implementation
   - Accuracy as for 2.
   - (Reference to absolute time)

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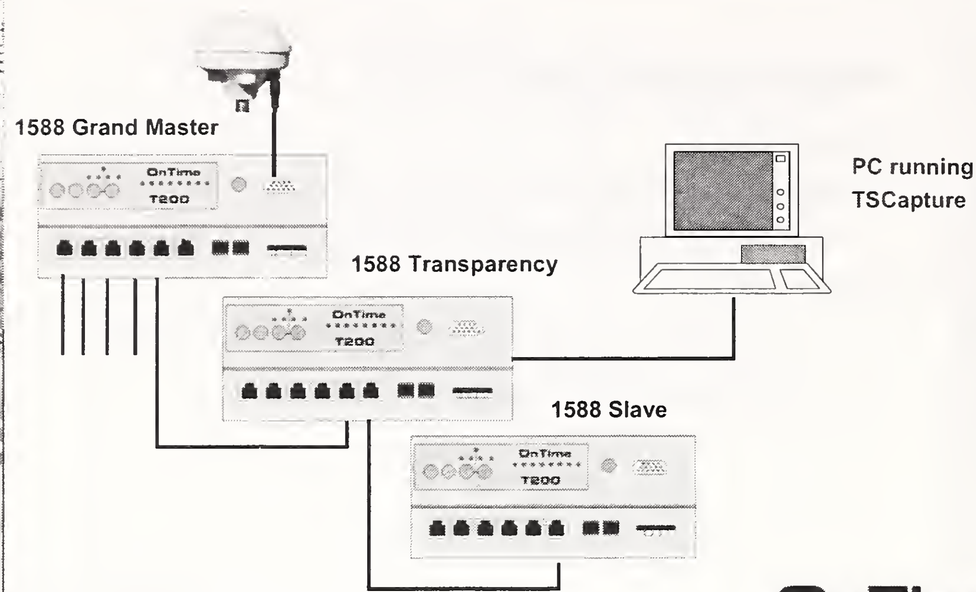
IEEE 1588 Ethernet Switch Transparency



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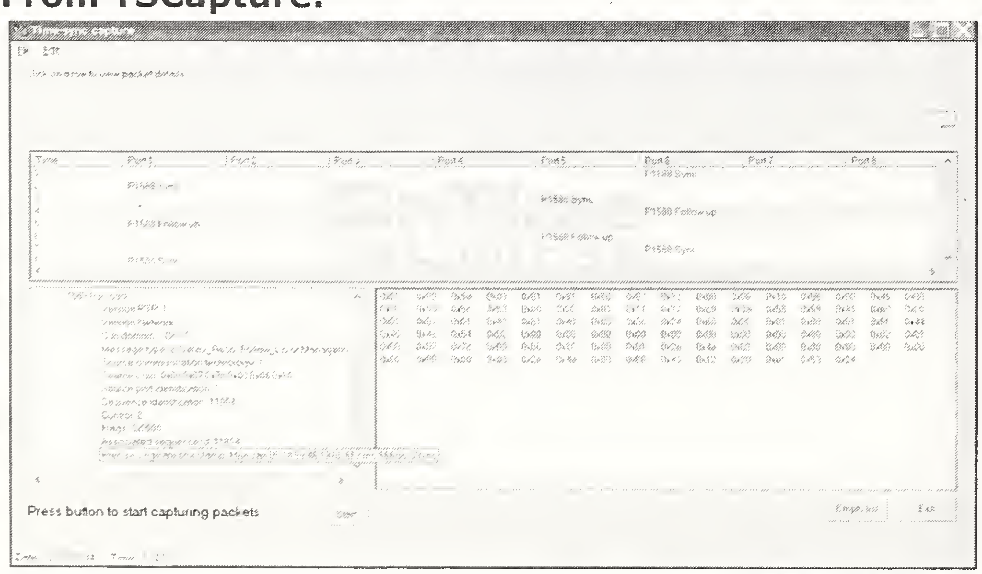
IEEE 1588 Ethernet Switch Transparency

From TSCapture:



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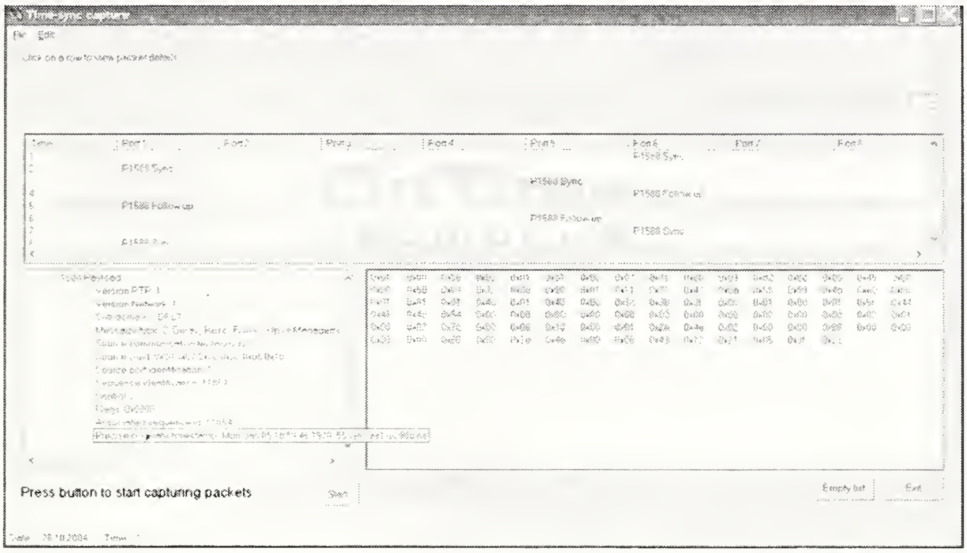
13

IEEE 1588 Ethernet Switch Transparency

From TSCapture:



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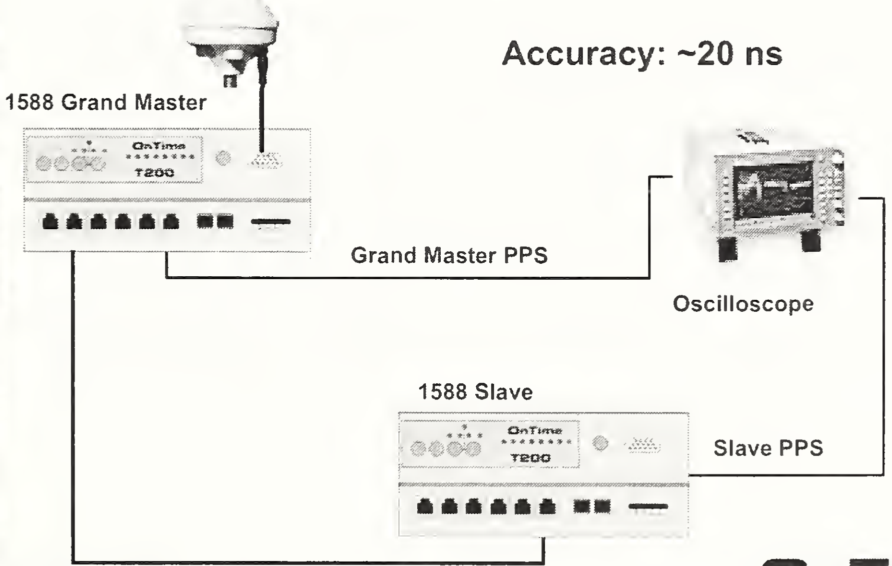
IEEE 1588 Ethernet Switch Transparency

Accuracy: ~20 ns

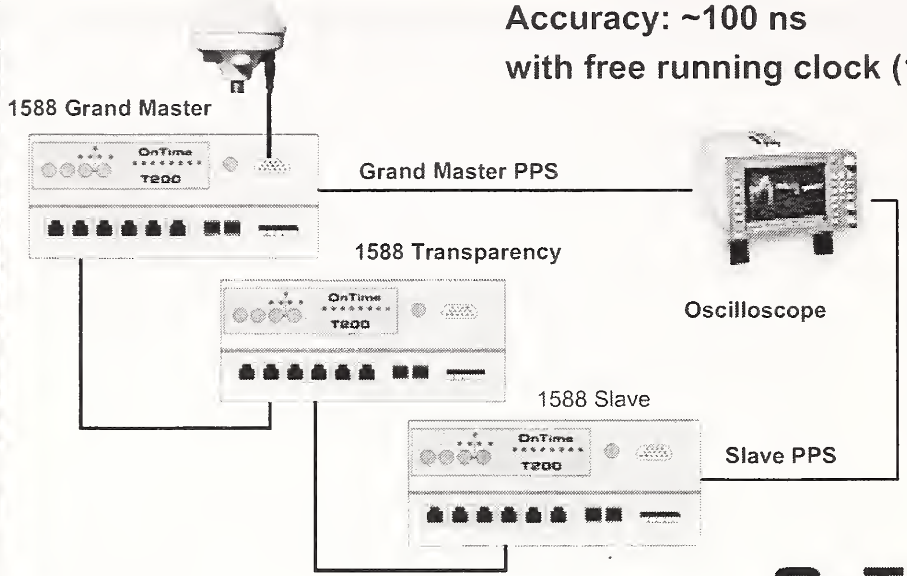


OnTime networks

15

IEEE 1588 Ethernet Switch Transparency

Accuracy: ~100 ns
with free running clock (1)



OnTime
networks

16

IEEE 1588 Ethernet Switch Transparency

Summary:

- Simple configuration
- Faster setup
- Less interoperability problems and easier conformance
- Accuracy as for a corresponding Boundary clock
- Solves one of the main disadvanteges related to the SNTP/NTP

OnTime
networks

Bridging Networks with PTP

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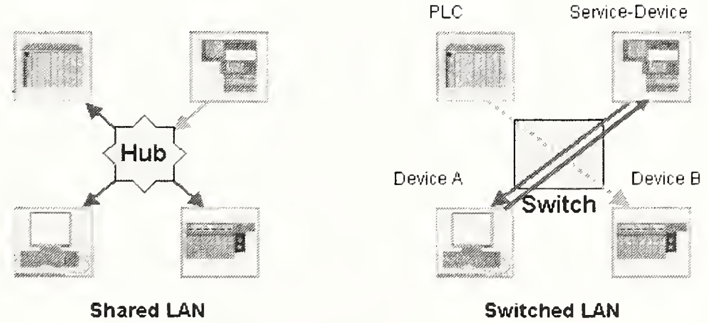
Networking changes

from shared medium ...
(allowing just one transaction in a moment of time)



... to switched systems
(allowing multiple transactions)

Switching (MAC-Bridging) facts

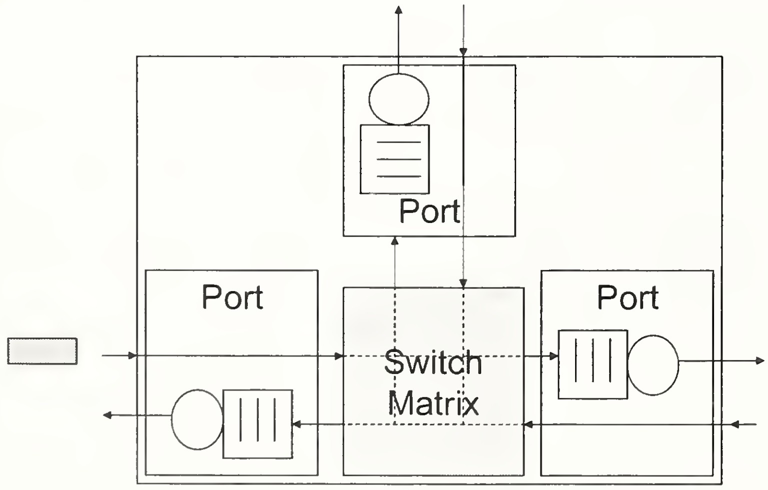
- Term „Switch“ is used to indicate Bridging at Data Link Layer
- Switches are widely used today
- Switches offer a set of useful features:
  - support Full-Duplex operation (FDX): no CS, no MA, no CD (IEEE802.3x)
  - Little configuration effort
  - Priority support (IEEE802.1p, IEEE802.1Q)
  - Bridging different speeds and different IEEE802 protocols (e.g. wireless)
  - Flexible structure through Virtual LANs (IEEE802.1Q)
  - Independent of the network structure and the size of the network
  - High throughput
  - **Almost** transparent to the end nodes

... but not in terms of delay and delay variation!!!

(applies to Routers as well)

Simple Example

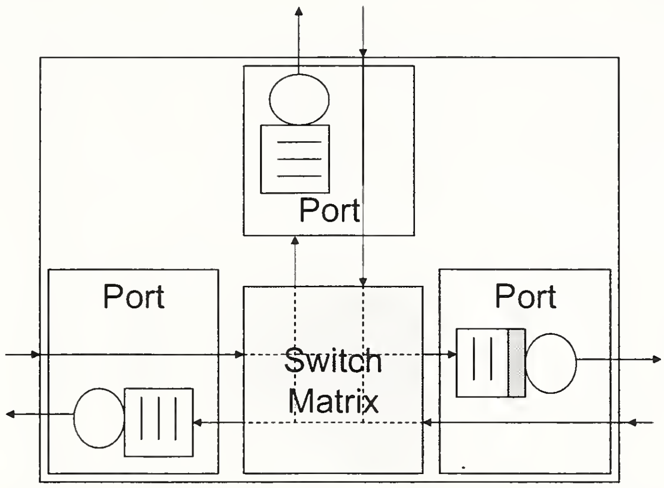
- Store and Foreward Switch can be modeled as a Queueing system



Assumption: Output queue is empty (best case)

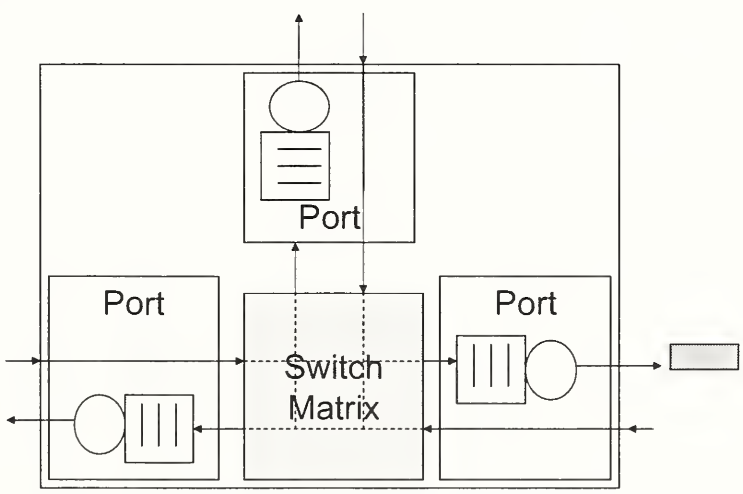
Simple Example

- Store and Foreward Switch can be modeled as a Queueing system



Simple Example

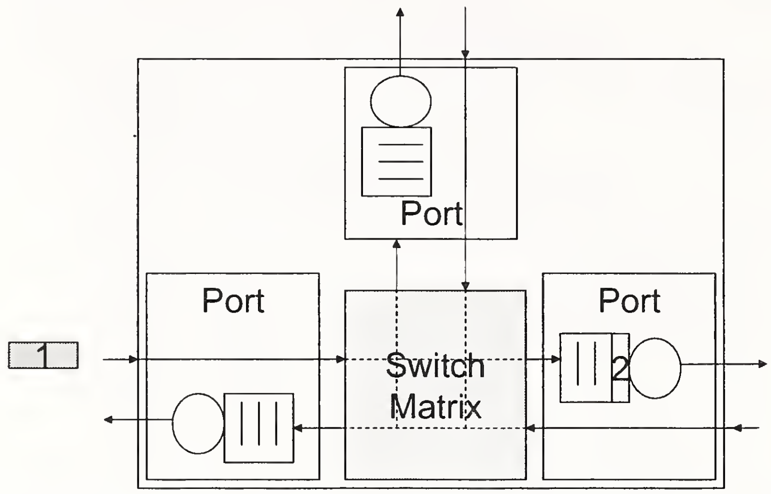
- Store and Foreward Switch can be modeled as a Queueing system



→ Delay = (Framesize + IFG)/C

Simple Example

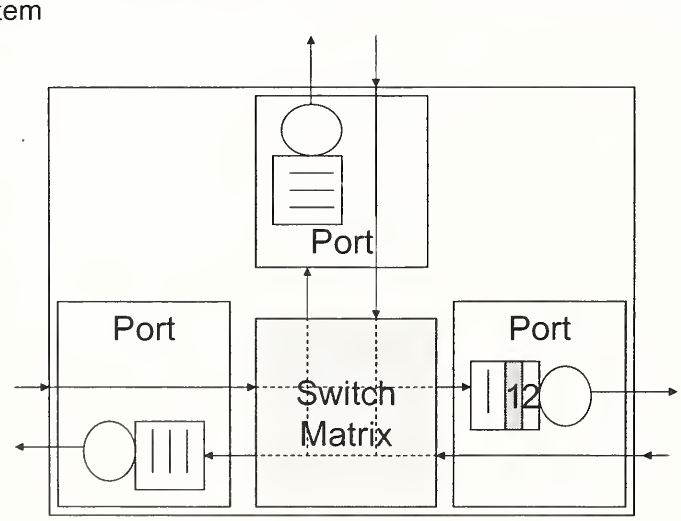
- Store and Foreward Switch can be modeled as a Queueing system



Assumption: Output Queue serves a long frame (bad case)

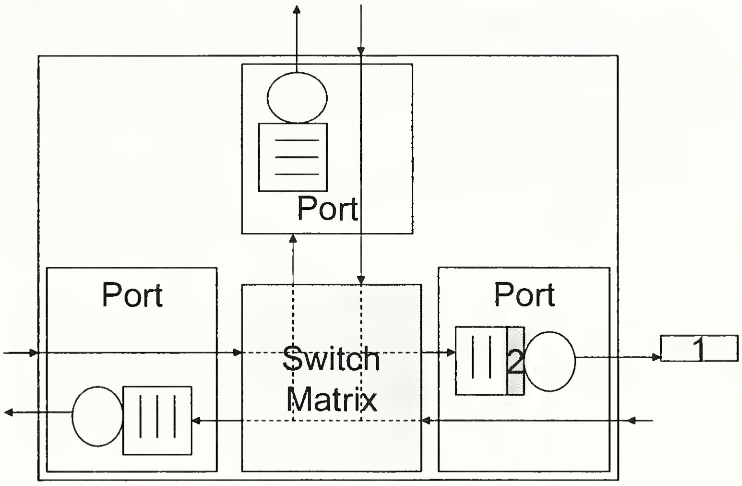
Simple Example

- Store and Foreward Switch can be modeled as a Queueing system



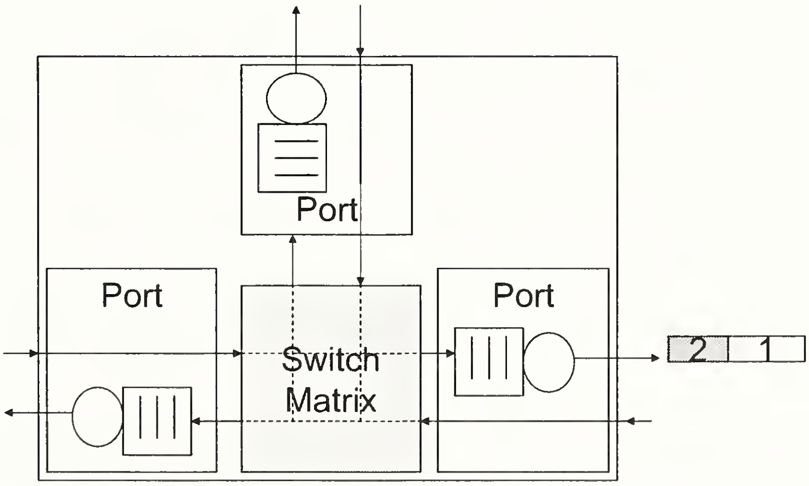
Simple Example

- Store and Foreward Switch can be modeled as a Queueing system



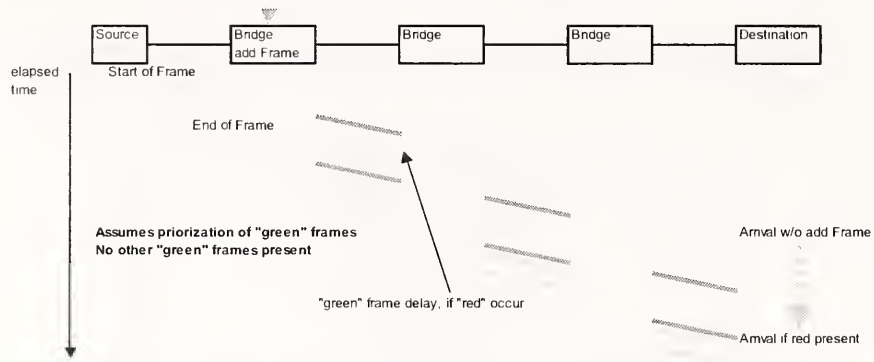
Simple Example

- Store and Foreward Switch can be modeled as a Queueing system



→ Delay = (Framesize1 + Framesize2+2*IFG)/C

Delay in Switches and Delay variation



Additional Delay (for **one** highest priority Frame) =
number_of_Bridges * max_Frame_size/data_rate
(but there may be other "green" frames ...)

Approaches to address bridging jitter

- Do some Filtering
  - Statistical methods to filter variation in delay
  - Ignore Messages with extreme long delay

>> this implies symmetrical and statistical network behaviour (which is not the case for Voice, Large File Transfers, process data and others)

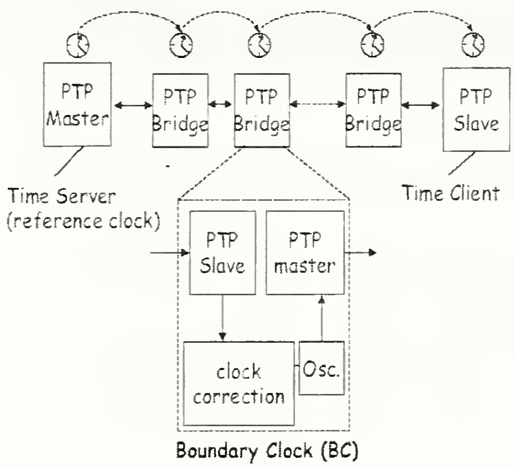
- Clock Gateway

Boundary clock may not fit in the switch world

- Priority Schemes

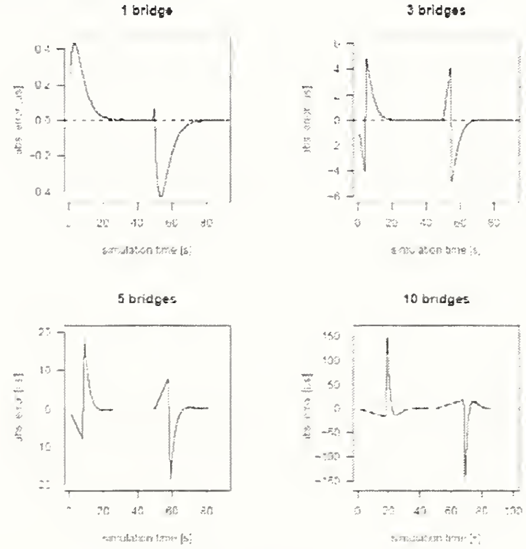
Needed, but examples above are priority based

Boundary Clock



- is more appropriate for gateways than for switches
- Boundary Clocks add delays which causes inaccuracies
- IP/UDP is used for most Sync protocols, but switches act at media access level
- Cascading boundary clocks have some negative impact on accuracy

Absolute error of Sync for different number of cascaded bridges using boundary clocks



Jasperneite, Weber, Shehab: Enhancements to the Time Synchronization Standard IEEE-1588 for a System of Cascaded Bridges, IEEE Workshop WFCS 2004, Vienna

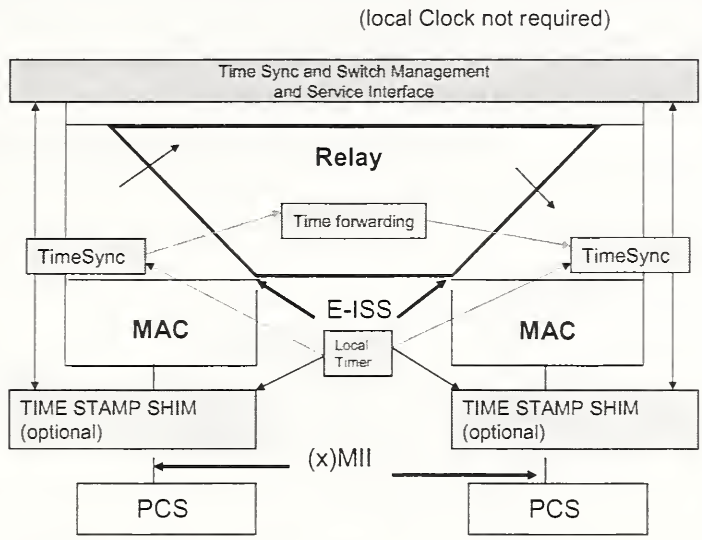
1588 could handle switching issues

- 1588 protocol elements are very useful in this domain
  - Sync/FollowUp
  - DelayReq/Res
- 1588 does not rely on UDP/IP
  - Header with 1588-EtherType and 1588-MAC Addresses has the same quality
- 1588 technical extension task force addressed this
  - Introduce new device type PTP Bridge
  - Add fields for additional Bridge Delay in Sync/FollowUp
  - Limit the scope of Delay measurement to adjacent nodes

IEEE 802 sync activities

- IEEE 802(.1) has no activities in synchronization in switched networks
- IEEE 802(.3) introduces some synchronization
  - for link coordination as in EPON(Ethernet Passive Optical Netw.)
- IEEE 802(.3) has a study group for synch Ethernet in homes
  - Investigating sync protocols
  - Switching is an important issue there
- 1588 could be used ...
  - 1588 has done a lot of investigations in this field
  - Number of sync protocols in IEEE should be limited

Architecture of Time Sync in Switches (from IEEE 802-model)



Conclusion

- There is no widely accepted sync protocol at IEEE 802 level
- Bridged networks need an approach for sync at Bridge level
- A sync protocol for IEEE 802 conformant sync shall fit in the IEEE architecture
  - MAC services
  - Relay function at link level
- IEEE 1588 should do this with a liaison to IEEE 802

HIRSCHMANN
Automation and Network Solutions

Implementation Results of an IEEE1588 Boundary Clock

Hirschmann Electronics GmbH & Co. KG
Automation and Network Solutions
Dirk S. Mohl

WWW.HIRSCHMANN.COM

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IEEE 1588 Implementation Results

- Overview
- Network Management: SNMP and IEEE1588
- Other Time Sync. Protocols: SNTP and IEEE1588
- Boundary Clock in Switches: Results of Cascading IEEE1588
- IEEE 1588 Usage in Industrial Ethernet - IAONA
- Summary

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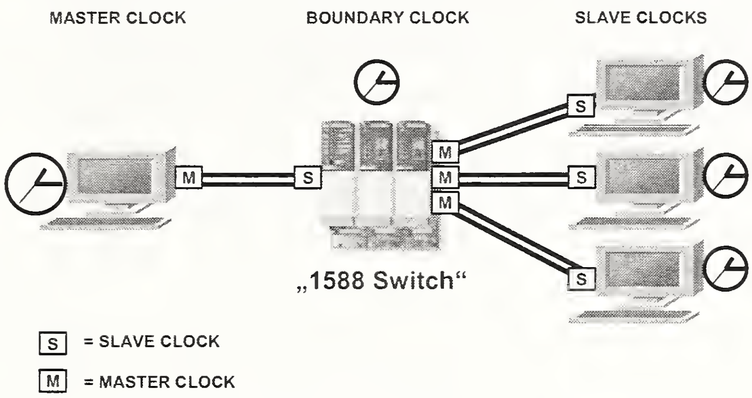
IEEE 1588 Switch: Boundary Clock on Layer 2

IEEE 1588 Boundary clocks in switches

- only point to point connections:
  => nearly no delay jitter between master and slave
- internal queuing delay / jitter of switch not relevant



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Implementation Features

Software- Architecture

Operating System Independent Design

- OS independent Protocol Stack
  (IEEE1588 Implementation)

- OS Abstraction Layer
  (Clock Interface, Timestamp Interface, Port Interface (Packets))

- OS dependent
  (Tasks, Timer, Semaphors, Sockets)

- OS and Hardware dependent
  (Network Driver, Clock Driver, Timestamp Driver)

Hardware- Architecture

- well defined Interfaces, available Interfaces
  (CPU, Ethernet: Medium or MAC<=>PHY

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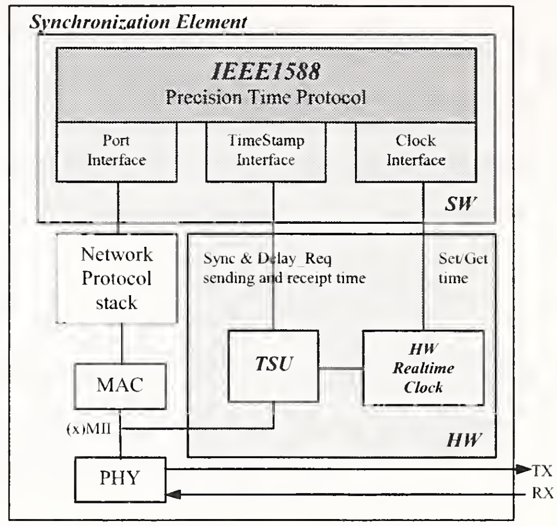
Implementation Overview

Software:
IEEE1588 Protocol with drivers

Network Stack: Operating System

Hardware:
Time Stamp Unit and high precision Real-time Clock



TSU - TimeStamp Unit

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Summary of Software Stack

- **IEEE 1588Implementation**
  - based on IEEE1588-2002
  - synchronization, follow up, delay measurement
  - best master clock algorithm
  - full IEEE 1588 management support
  - portable code
  - adaptation layer for pure software or hardware based time stamping / clock generation
  - SNMP MIB (VxWorks)
  - time representation of nsec : UINT32
  - VHDL: Timestamp generation and high precision clock
- **Implementations under Linux, VxWorks and Windows**

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Cooperation ZHW - Hirschmann

HIRSCHMANN
Automation and Network Solutions

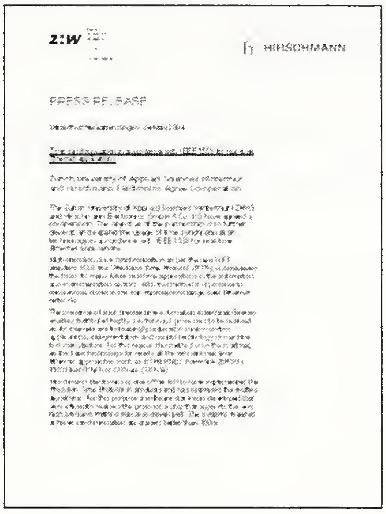
Make IEEE 1588 Code available

The cooperation was signed in May 2004

ZHW takes care of maintenance, sale and support of Hirschmann IEEE 1588 stack

Customer can buy code (SW) and IP core (HW) as source or binary

ZHW
Züricher Hochschule Winterthur
/ Zurich University of Applied Sciences



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IEEE 1588 Management by SNMP

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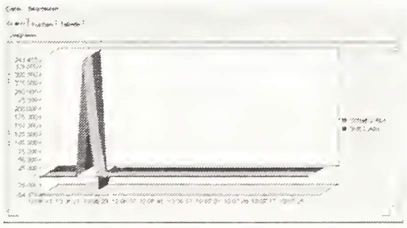
SNMP is by now the most frequently used protocol on network devices.

There are tree version of SNMP available, two of them are common:

* SNMP V1 - very simple authentication
SNMP V2c - enhanced variable types (not often used)
* SNMP V3 - secure authentication, encryption, signature, acces control

Since this protocol is the basic management protocol in managed switches and routers, it is obvious that it also could be used to configure and observe IEEE1588 parameters.

E. g. drift and offset



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IEEE 1588 Management by SNMP

SNMP is organized in an hierarchical tree structure

Every object or object group has its name and its unique object identifier

e.g. the object ID of internet is 1.3.6.1
and so
hmNetPTPEnable is
1.3.6.1.4.1.248.14.2.3.40.1.1

The number is used by the protocol to access data

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IEEE 1588 Management by SNMP

Every variable is part of the Management Information Base (MIB).

The definition of this database is standardized.

Every Object in the database has the following information:
Numeric Identifier, Name, Type (e.g. integer), access (e. g. read only) ...

It is very easy to make PTP objects available for SNMP:

Normally for the target platform (operating system) a compiler is available which generates a C- skeleton code out of the MIB- file.
In this code access to the value has to be added.

```
case hmNetPTPObservedDrift:   /* INTEGER, read-only */
{
switch ( request )
    {
case IDB_GET_NEXT:
buildNextInstance(...);
/* FALLTHRU */
case IDB_GET:
if ( rc == OK )
        {
            int observedDrift=0;
            observedDrift = PTP_T_getObservedDrift();
            return observedDrift;
        }
break;
case IDB_VALIDATE:
...
```

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IEEE 1588 how to come to an official MIB

Do it exactly the same like IEEE802 example: LLDP

- MIB is part of an IEEE standard
- MIB is in the "std" branch

Proposal:
iso -> std -> ieee1588 -> ptpMIB
or
iso -> std -> IEC61588 -> ptpMIB
object ID could be
1.0.1588.1 or 1.0.61588.1

Open Question:
Timeframe vs. other options: RFC

Table 11-3—Basic-TLV variable/remote-systems MIB object cross-references

TLV Name	TLV Variable	LLDP remote system MIB object
Chassis ID	Chassis ID subtype	lldpRemChassisSubtype
	Chassis ID	lldpRemChassisId
Port ID	Port ID subtype	lldpRemPortIdSubtype

12.1 LLDP MIB module[3]

In the following MIB module, should any discrepancy between the DESCRIPTION text and the corresponding definition in clauses 10 and 11 occur, the definition in clauses 10 and 11 shall take precedence

```
LLDP-MIB DEFINITIONS ::= BEGIN

IMPORTS
    MODULE-IDENTITY, OBJECT-TYPE, Integer32, Counter32, NOTIFICATION-TYPE
        FROM SNMPv2-SMI
    TEXTUAL-CONVENTION, TimeStamp, TruthValue
        FROM SNMPv2-TC
```

```
ccitt
iso
  std
    iso8802
      ieee802dot1
        ieee802dot1mibs
          lldpMIB
  org
    dod
```

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IEEE 1588 in cooperation with SNTP

NTP (Network Time Protocol) and SNTP (Simple NTP) are currently the most widely spread

SNTP: typically +/- 50ms, about a minute to reach precision

NTP: typically +/- 50ms, alos up to ms and better, hours to reach high precision

IEEE1588: +/- 50ns and better, better than a minute to reach precision

Currently used time servers, atomic clocks or GPS receivers use SNTP / NTP.
But even if IEEE1588 servers will be available a wide installed base will still exist.
Also many end devices need time but no precision: will still use SNTP / NTP

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IEEE 1588 in cooperation with SNTP

Requirements
- precise absolute time including day
- precise relative time

IEEE1588 synchronizes SNTP server
=> with 1588 a SNTP server gets time nearly as precise as from GPS and so can distribute this time

SNTP synchronizes a 1588 clock
=> worse accuracy is transported to precise IEEE1588 network

Solution:
Filter for SNTP/NTP time to IEEE1588
e. g. only Seconds, minutes hours and days are taken from SNTP

Pay attention to "Time Loops" : SNTP => 1588 => SNTP, e.g. SNTP anycast

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IEEE 1588 Test results: 4 Switches

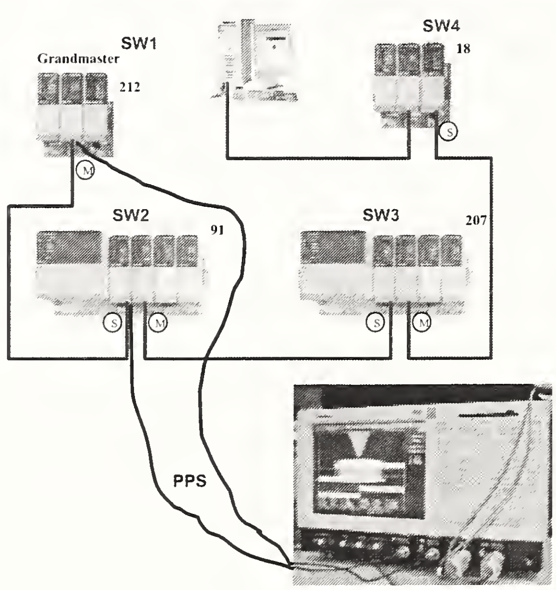
Test Setup #1

1 Grandmaster
3 cascaded clocks

connected with
100 Mbits/s

Every device provides
Offset and Drift over
SNMP

Two devices generate
PPS out



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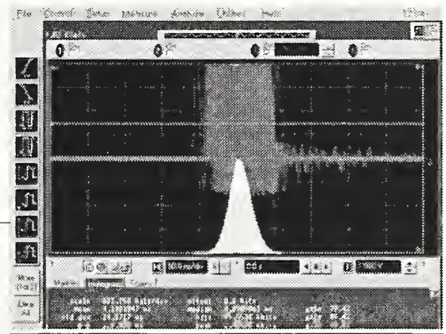
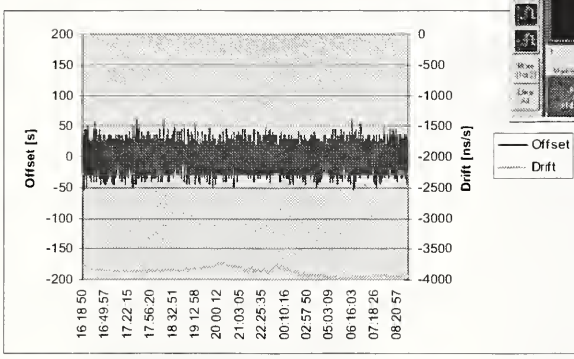
IEEE 1588 Test results: direct connection

Switch 2:
1st switch behind Grandmaster

observed Offset and Drift





Offset measurement

Peak to Peak: 120ns
=> + / - 60 ns

Standard deviation: 15ns

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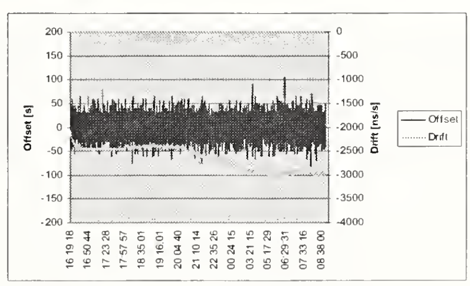
IEEE 1588 Test results: 1 / 2 switches in between

Switch 3:
2nd Switch after Grandmaster

Offset higher variation than previous Switch

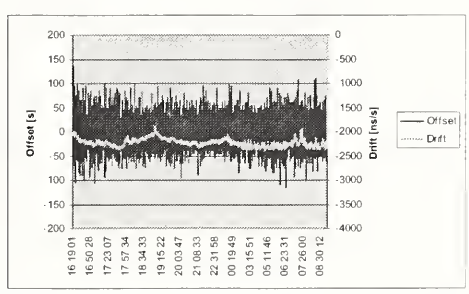
approx. +/- 110ns



Switch 4:
3rd Switch after Grandmaster

again Offset higher variation and also higher drift variation

approx. +/- 150ns



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IEEE 1588 Test results: 10 switches

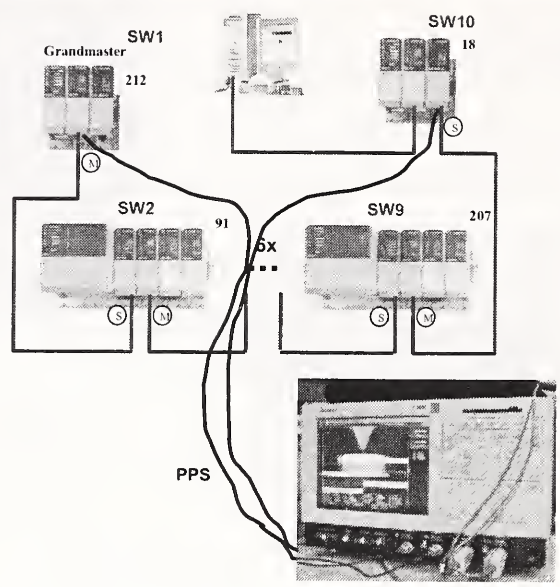
Test Setup #2

1 Grandmaster
9 cascaded clocks

connected with
100 Mbits/s

Every device provides
Offset and Drift over
SNMP

Two devices generate
PPS out



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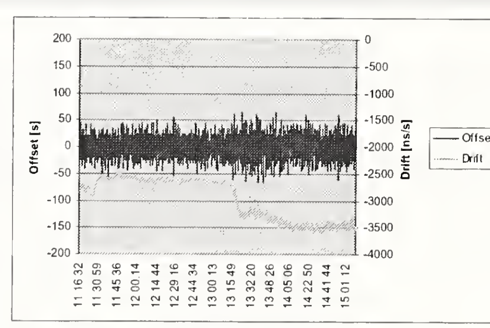
IEEE 1588 Test results: higher cascading

Switch 2
again Offset in range +/- 60ns

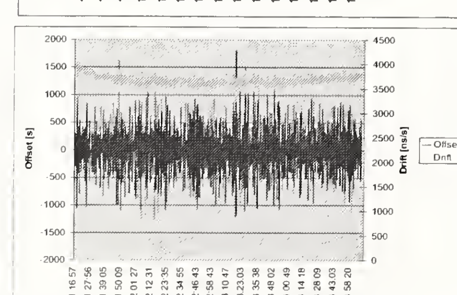
Oscillator sensitive to temperature



Switch 10
9th switch behind Grandmaster

Offset in Range +/- 1500ns
higher variation in Drift

Runaways during temperature change



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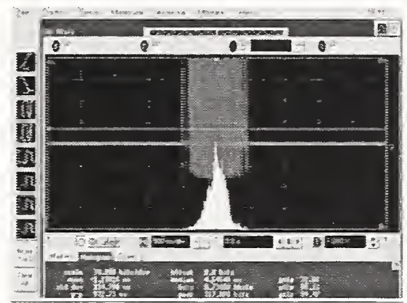
IEEE 1588 Test results: higher cascading

Switch 5
4th switch behind Grandmaster

measured Offset and Drift

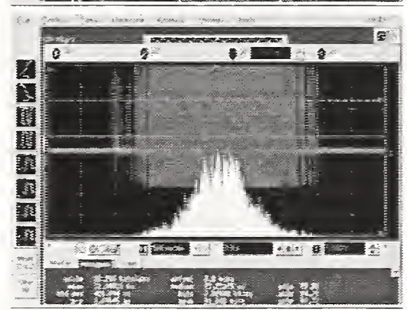
Peak to Peak: 1000ns => +/- 500 ns



Switch 10
9th switch behind Grandmaster

measured Offset and Drift

Peak to Peak: ns => 3000ns +/- 1500 ns



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IEEE 1588 Test results: reconfiguration

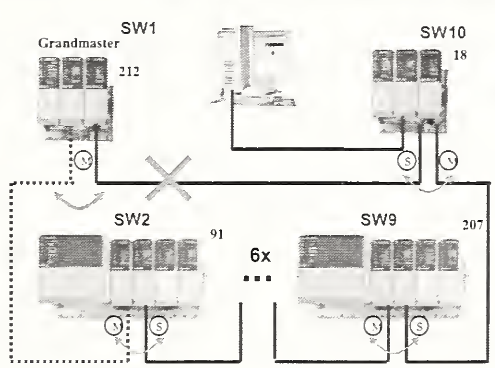
Test Setup #3

1 Grandmaster
9 cascaded clocks

connected with
100 MBits/s

HIPER Ring:

Fast Reconfiguration



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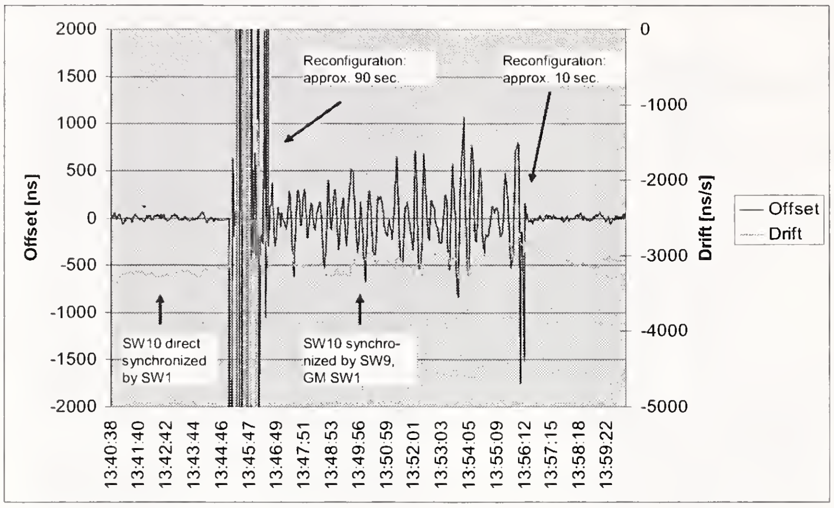
IEEE 1588 Test results: short to long path



Switch 10 and Switch 1
Fall over from direct connection to in between 8 switches and back.

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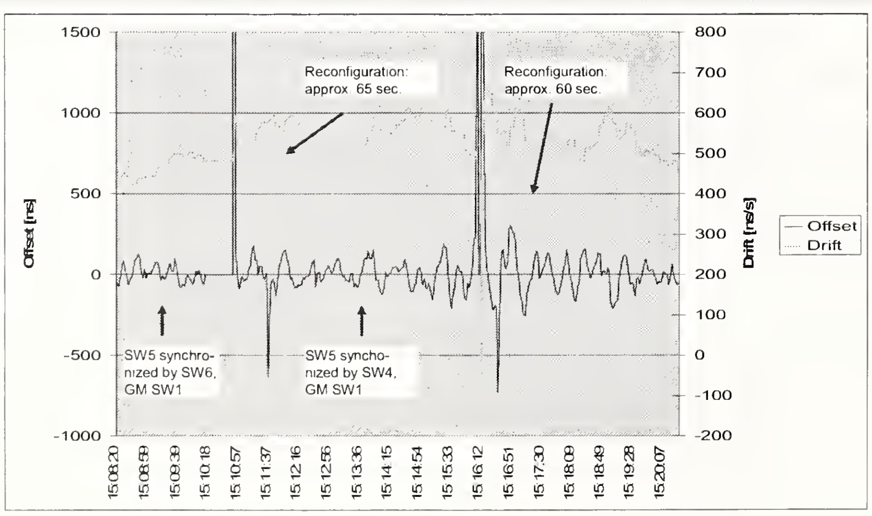
IEEE 1588 Test results: different path



Switch 5 and Switch 1
Fall over from connection over SW 10 to SW 6 to connection over SW 2 to SW 4 and back.

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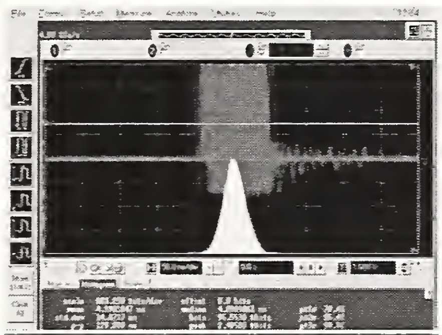
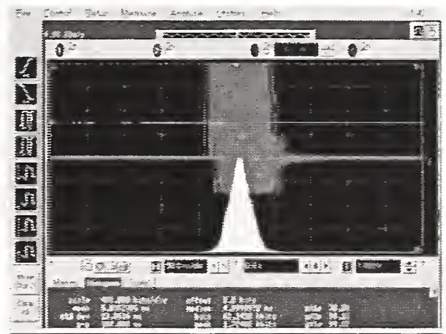
IEEE 1588 Test results: low vs. high traffic





no traffic

high traffic

=> no influence observable

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iaona

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IAONA and IEEE1588

➔ *IAONA Main Objective in 1999:*
„Establish Ethernet TCP/IP as the future standard in Industrial Communication"

IAONA was founded in 1999 at the SPS/IPC/Drives in Nuremberg as an alliance of meanwhile more than 130 leading international manufacturers and users of automation systems.

The task of IAONA is to commonly work out specifications and guidelines to be used in order to force the spread of Ethernet in the fields described above.

IAONA takes the view that a realization of these aims can only succeed by applying the principle of the "open source" model. That means a consequent spread out of all specifications over a broad public

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IEEE 1588 - Application example for Real-Time Cells

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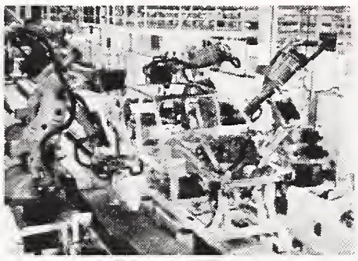
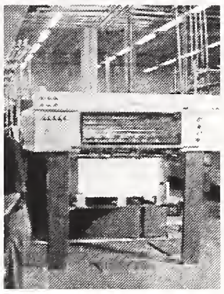
Several real-time segments are synchronized beneath each others

cooperating robots:
several robots work together the same time with the same workpiece



Machines consisting of several units:
e. g. printing machines, the paper is hand over from one unit to the next



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IEEE 1588 - Summary

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- IEEE 1588 should be supported by Ethernet Switches, if precision has to be distributed in the network
- IEEE1588 Stack available
- Management via SNMP makes things easier
- IEEE1588 and SNTP will both be necessary
- Cascading depth low: each switch adds its jitter of about +/-60ns to precision
- In higher cascading depth the accumulated precision is more than the jitter of a switch, especially control loop events (e. g. due to temperature changes) contribute to that jitter.
- IAONA may help to promote acceptance of IEEE1588

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PHYs and symmetrical propagation delay

Prof. Thomas Müller (ZHW)
Alexander Ockert (Hilscher)
Prof. Hans Weibel (ZHW)

Basics

D.1.1 message timestamp point

The PTP message timestamp point, clause 6.2.2.3, shall correspond to the leading edge of the first bit of the octet immediately following the Start Frame Delimiter octet of an Ethernet packet, [802.3]. This point is illustrated in Figure C-1.

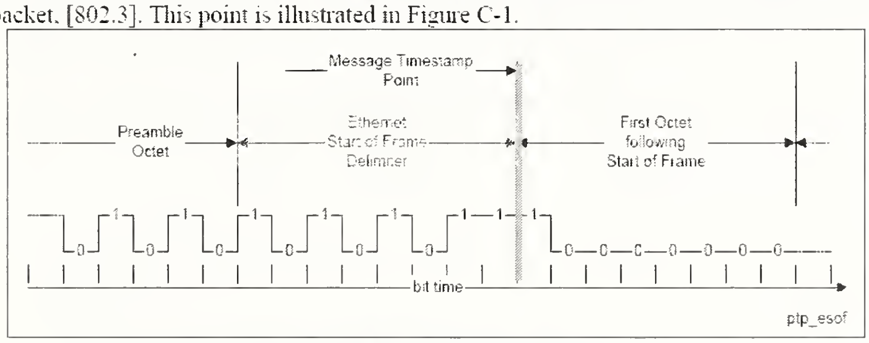
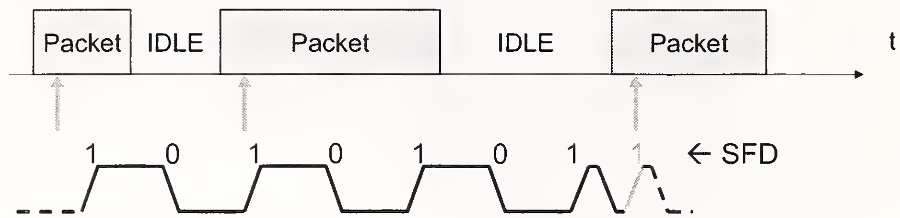


Figure C-1: Message timestamp point

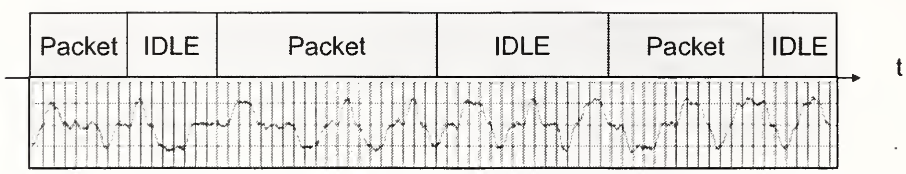
How to detect an Ethernet Frame?

Easy on 10 Base-X Technology:

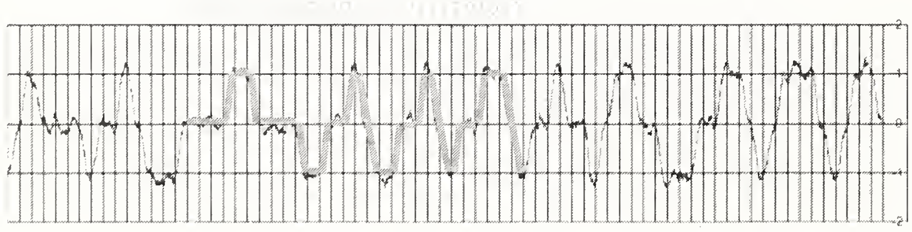
- Distinct packages with SFD as synchronization point
- Machester coding



100 Base-TX: Continuous, scrambled Signal

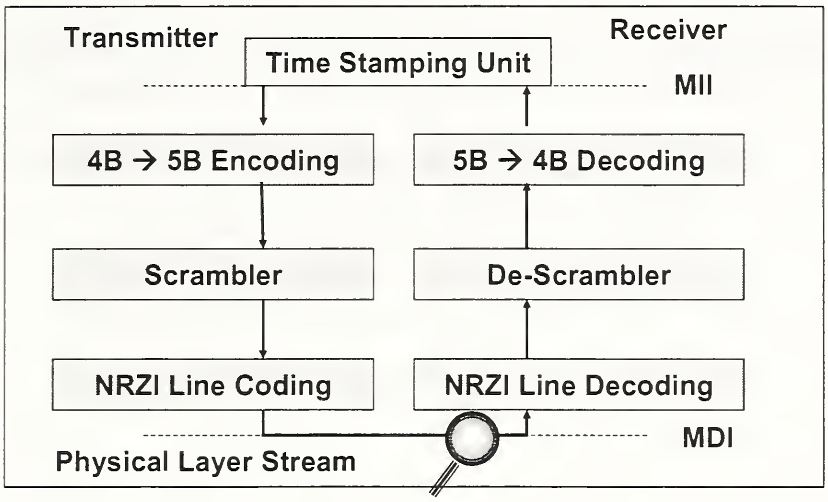


Line Coding 100Base-TX Signal



MLT-3 Coding:

Locating „Time Stamping Unit“ at MII

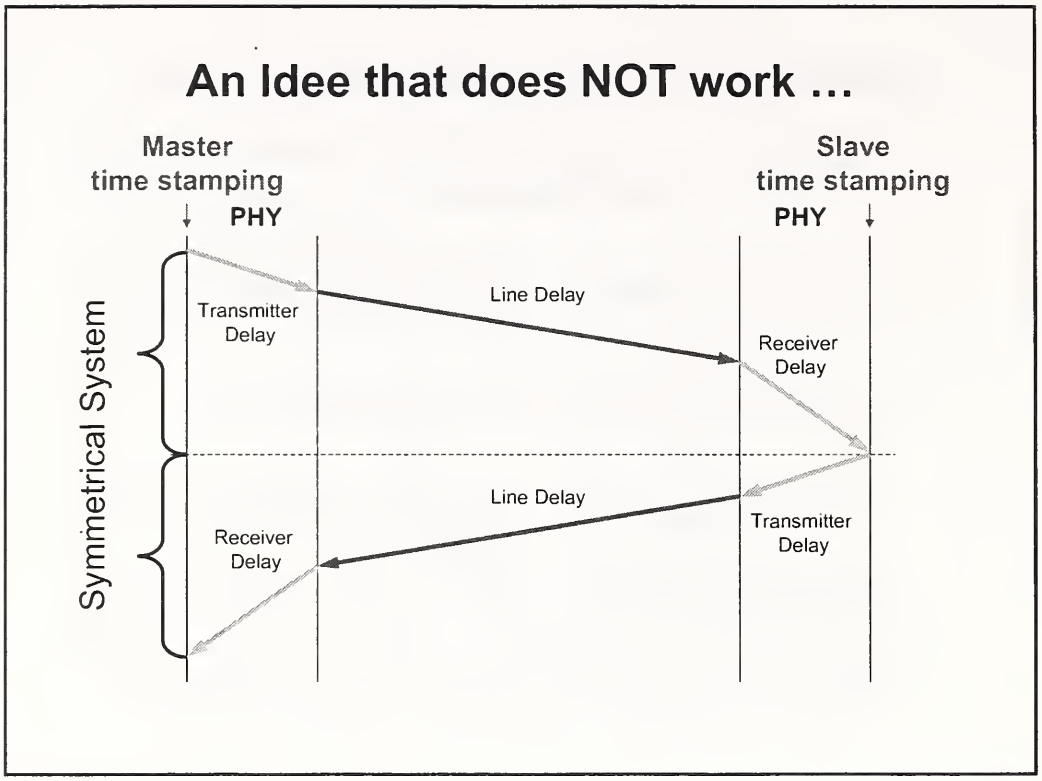


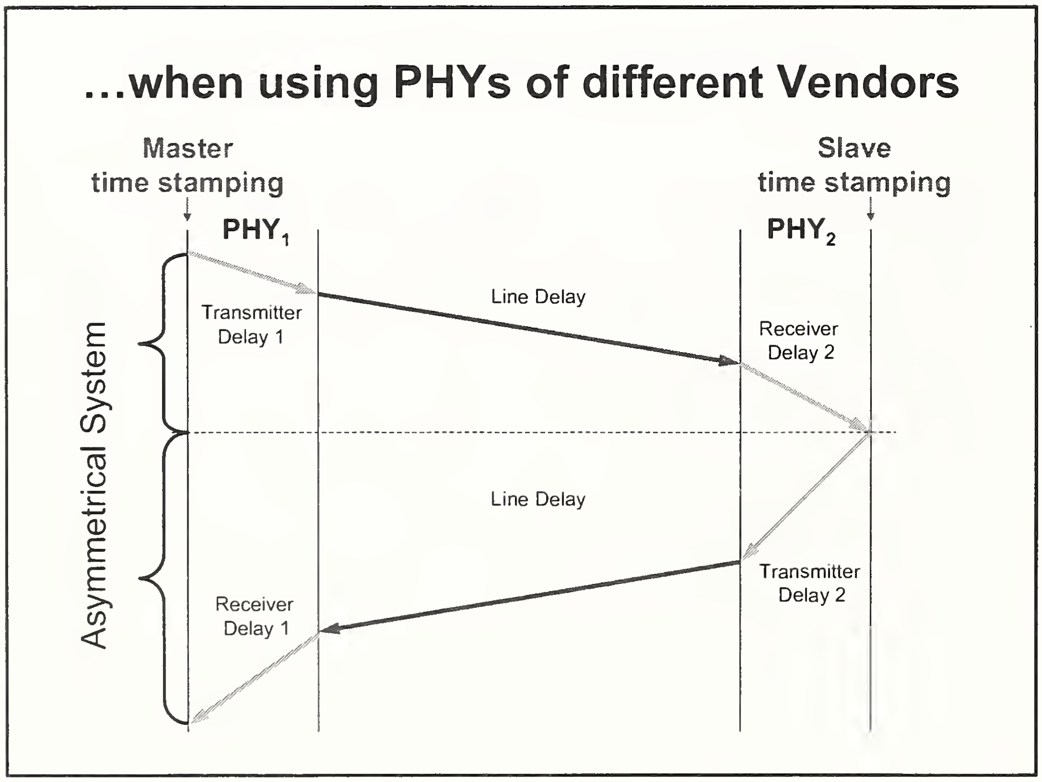
when using common PHYs with exposed MII
→ only possible to get time stamps at MII

Phy Transmit / Receive Delay

PHY with exposed MII full-duplex, 100 Mbps	Transmit Packet Assertion [bits]:	Receive Packet Deassertion [bits]:
IEEE 802.3 Standard (max.)	14	32
NSC DP83843 PHYTER	6	21.5
Intel Dual PHY LXT973	5	17

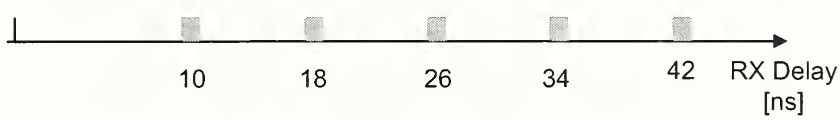
- Transmit Delay and Receive Delay are not equal (Difference of Factor 3)
- Delays are Vendor specific
  → Local Compensation needed


An Idee that does NOT work …
Master
time stamping
PHY
Slave
time stamping
PHY
Symmetrical System
Transmitter
Delay
Line Delay
Receiver
Delay
Line Delay
Transmitter
Delay
Receiver
Delay

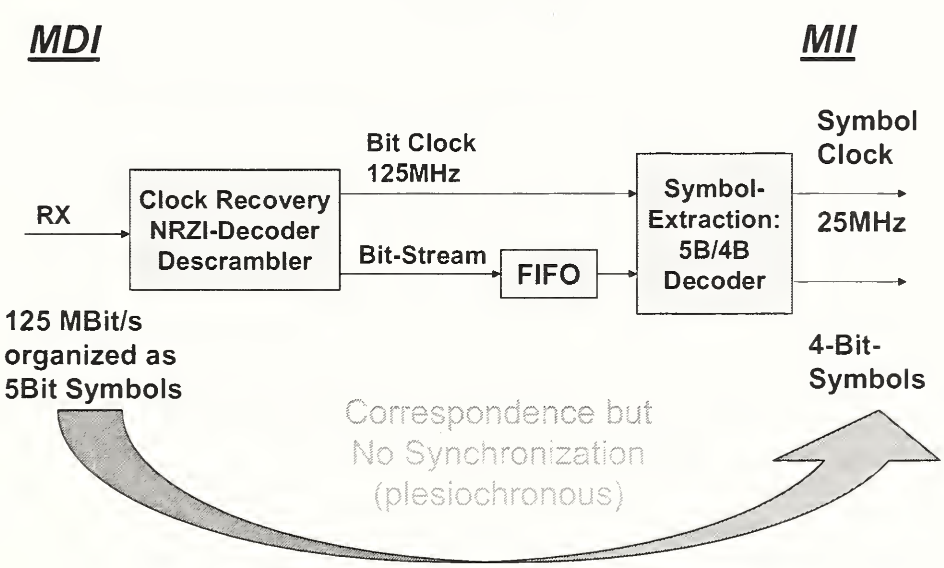

…when using PHYs of different Vendors
Master
time stamping
PHY1
Slave
time stamping
PHY2
Asymmetrical System
Transmitter
Delay 1
Line Delay
Receiver
Delay 2
Line Delay
Transmitter
Delay 2
Receiver
Delay 1

Synchronisation Problems

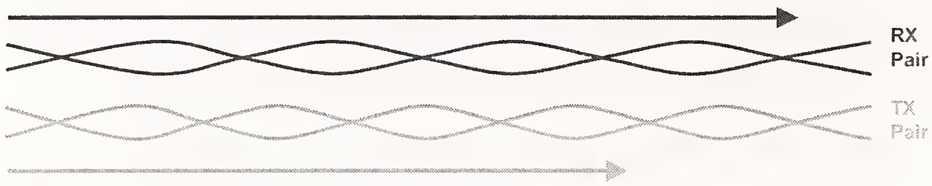
- SW-Driver should compensate the constant Transmitter Delay and Receiver Delay
- But RX Delay is not always the same
  - After each synchronisation RX Delay lockes in to raster of 8 ns (5 states)
  - But then jitter is constant and low (< 1ns)



Raw physical model of a Receiver



Another Source of Errors: Line Delay Skew



Different twist rate of twisted line pairs
leads to Delay Skew (difference between propagation delays of transmit and receive lines)

- CAT 5/6: up to 50 ns per 100 meter cable (IEC 11801)
- CAT 7: up to 30 ns per 100 meter cable (IEC 11801)
- Real cables are better than IEC 11801 specifies
- PROFINET quad-cable: 8 ns per 100 meter cable

Further details which should be taken into account...

If MII and MAC represent two different clock domains then...

- MAC layer clock and MII.tx_clk are not synchronized

  → Error in estimation of "Transmit Message Timestamp"

- MAC layer clock and MII.rx_clk are not synchronized

  → Error due sampling of MII.rxd[0..3] to detect Start-Of-Frame-Delimiter

Many thanks for your attention!

Prof. H. Weibel (ZHW)

Zurich University of Applied Sciences
Institute of Embedded Systems
http://ines.zhwin.ch

Report of the IEEE 1588 Task Force on User Requirements

Silvana Rodrigues – UR Task Force Chair

Zarlink Semiconductor

Steve Zuponcic - UR Secretary

Rockwell Automation

Applications of Interest

- Industrial Controls
  - Robotics
  - General Motion Control
  - Industrial Networking
  - Industrial Networking with RTE traffic
- Measurement and Control:
  - Process Control Applications
- Test and Measurement:
  - RF Spectrum correlation, I/Q
  - Signal Correlation, Stimulus-Response, and High Speed Logic
  - Low Frequency Devices
- Military Test

Applications of Interest cont'd

- Telecom
  - Slave clock
  - Frequency follower/generator
  - Time base follower/generator
- Automotive
  - On-Board Control
- Security
- Power grid substation automation and metering automation

Topics

- Performance
  - A matrix on requirements for several applications was created
- API interface
  - Needs a better understanding of all the system issues
  - More study is needed on this topic
- Topology
  - Diverse requirements across applications
  - Need more study on the topology for different applications
- Redundancy
  - No need for redundancy for traditional Test & Measurement equipment
  - Need more study on how the requirements can be met without penalty for applications that do not need it

Performance Requirements

Industry/ Application	**Performance Level (Accuracy)**
Industrial Controls/ Robotics	Less than 100μs
Industrial Controls/ General Motion Control	From 1ns to 10μs
Industrial Networking	From 10μs to 100μs
Industrial Networking with RTE traffic	From 1ns to 1μs
Measurement and control: Process Control Application	From 10μs to 1ms
Test and measurement: RF Spectrum correlation, I/Q	Less than 1ns
Test and measurement: Signal correlation, stimulus response, high speed logic	Less than 10ns
Test and measurement: Low frequency devices	From 100ns to 1μs

Performance Requirements cont'd

Industry/ Application	**Performance Level (Accuracy)**
Military test	Less than 100ps
Telecom: Slave clock (freq. Follower/generator)	Time Accuracy at network edge: <25ns short-term <2μs medium-term <5μs long-term Time variance across clock: <25ns short-term <100ns medium-term <100ns long-term Holdover Frequency Accuracy: +/-1 x 10e-10. Free-run Frequency Accuracy: +/-1.6 x 10-8 < δF < +/-1 x 10e-7

Performance Requirements cont'd

Industry/ Application	**Performance Level (Accuracy)**
Telecom: Equipment clock (freq. Follower/generator)	Time Accuracy at network edge: <250ns short-term <2μs medium-term <5μs long-term Time variance across clock: <40ns short-term <100ns medium-term <100ns long-term Holdover Frequency Accuracy: +/-1.2 x 10-8 < δF < +/-4.6 x 10e-6. Free-run Frequency Accuracy: +/-0.2 x 10-9 < δF < +/-32 x 10e-6
Telecom: Time base clock (time base Follower/generator)	Time Accuracy at network edge: <25ns short-term <2μs medium-term <5μs long-term

Performance Requirements cont'd

Industry/ Application	**Performance Level (Accuracy)**
Automotive On-board control	From 1ns to 10μs
Power grid substation Automation and metering automation	From 1ms to 1s

New Requirements supporting the PAR

- Sub-nanosecond Accuracy
  - Test and Measurement: RF Spectrum correlation, I/Q
  - Military test
- Telecom applications
- Redundancy for Robustness
  - Requires further study

Conclusions

- Good understanding of the requirements for several different applications
- User requirement study supports the PAR topics
- Diverse requirements across applications for redundancy
  - Need more study on how the requirements can be met without penalty for applications that do not need it
- Topology requirements across applications are very diverse.

Report of the IEEE 1588 Task Force on Technical Extensions

John C. Eidson- TE task force chair

2004 Conference on IEEE 1588

Topics Discussed

- Accuracy issues
- Redundancy & fault tolerance
- SNMP MIBs
- Tagged frames
- Transparent boundary clocks
- Telecom related issues
- Mapping to DeviceNet

2004 Conference on IEEE 1588

Accuracy Issues

- Problem statement:
  - Re-examine tradeoffs that affect accuracy
  - Re-examine IEEE 1588 network components
  - Sub-nanosecond requirements
- Possible technical solutions:
  - Allow shorter sync intervals
  - Transparent boundary clocks
  - Extend timestamp resolution
  - Better oscillators

Redundancy & Fault Tolerance

- Problem statement:
  - Failure of the master clock
  - Failure of a network path
  - Very different requirements depending on application
- Possible technical solutions:
  - Redundant master clocks
  - Redundant time domains
  - Rapid re-computation or pre-computation of delays

SNMP MIBS

- Problem statement:
  - Most Ethernet based systems use SNMP
  - Most others do not
  - How does this relate to IEEE 1588 management messages
- Possible technical solutions:
  - Standard IEEE 1588 MIB
  - Based on or parallel to management messages

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Tagged Frames

- Problem statement:
  - Variable length Ethernet headers
  - Priority and/or VLAN tagging
  - IPV6
- Possible technical solutions:
  - Modify Annex D to allow variable length headers

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Transparent Boundary Clock

- Problem statement:
  - Accumulation of delay with cascaded boundary clocks
- Possible technical solutions:
  - 'Transparent clock': Sync, Delay_Req residence times are measured and used to correct time stamps.
  - Lots of issues and details but looks possible

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Telecom Related Issues

- Problem statement:
  - Need higher accuracy in telecom environment (no boundary or transparent clocks)
  - Need designed paths
  - Not all paths are Ethernet
- Possible technical solutions:
  - Shorter sync_interval
  - Layer 2 implementation
  - Shorter message length

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Mapping to DeviceNet

- Problem statement:
  - Need to map IEEE 1588 to DeviceNet
- Possible technical solutions:
  - Feasible map exists

Conclusions

- Topics recommended for inclusion in a PAR
  - Accuracy issues
  - Redundancy & fault tolerance
  - SNMP MIBs
  - Tagged frames
  - Transparent boundary clocks
  - Telecom related issues
  - Mapping to DeviceNet

1

Report of the Conformance Task Group

Øyvind Holmeide
oeyvind@ontimenet.com

OnTime networks

2

Conformance Task Group

Tasks:

- Handle questions and interpretations of IEEE1588
- Define minimum requirements for conformance
- Define test sets and test setups
- Plug-fests

OnTime networks

3

Conformance Task Group

Proposal for additions to the conformance section of the IEEE1588 standard:

- Define an appropriate interface for use in monitoring or measuring conformance

Why?

- Ease the task of making reasonable and useful tests of conformance to promote interoperability

OnTime networks

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Conformance Task Group

Current conformance section of IEEE1588:

- Very general
- No guidence on how to test or qualify an implementation

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Conformance Task Group

A full IEEE1588 implementation provides:

- Via the management messages:
  - Currently only visible over a network connection to the device,
  - The contents of the internal data sets that define all IEEE 1588 state governing the protocol: identity info, and the default, current, parent, port, global and foreign data sets.

OnTime networks

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Conformance Task Group

A full IEEE1588 implementation provides cont'd:

- Via normal messages SYNC, FOLLOW_UP, DEL_REQ, and DEL_RESP
  - Timestamps related to SYNC and DEL_REQ packets available from Masters
  - No visibility into inbound timestamps of the Slaves
  - Message interval timing, e.g. sync interval, delay request randomization

OnTime networks

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Conformance Task Group

This information will allow verification of:

- Packet formats and consistency of packet data with internal databases
- Aspects of packet contents related to topology: e.g. identification of the Grand master, steps removed...
- Aspects of packet contents related to time base: e.g. leap seconds
- Change of state in response to messages, e.g. testing the state machine of clause 7.3 of the standard
- Operation of the best master clock algorithms and related timeouts
- Protocol timing details such as sync interval, timeouts, burst timing, etc

OnTime networks

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Conformance Task Group

With only this information available, it is difficult to verify the following:

1. Actual performance of device clocks
2. Verification that things like stratum, variance, etc are correctly specified in the default data set or the observed variance and drift of the parent data set are correctly computed
3. The correctness of the randomization of DEL_REQ messages from slaves (due to the time involved to gather enough data to make a conformance decision)
4. The accuracy of synchronization between two clocks (a system issue)
5. Bias in a clock introduced either by the servo or internal latency asymmetry

OnTime networks

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Conformance Task Group

How to improve this?

1. Actual performance of device clocks
2. Verification that things like stratum, variance, etc are correctly specified in the default data set or the observed variance and drift of the parent data set are correctly computed

Proposal:

Get access to the clock oscillator output via a test point. This allows the fundamental stability and noise properties of the clock to be measured.

OnTime networks

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Conformance Task Group

How to improve this?

3. The correctness of the randomization of DEL_REQ messages from slaves (due to the time involved to gather enough data to make a conformance decision)

Proposal:

Management message access to invoke the random number generator(s) to measure its statistical properties

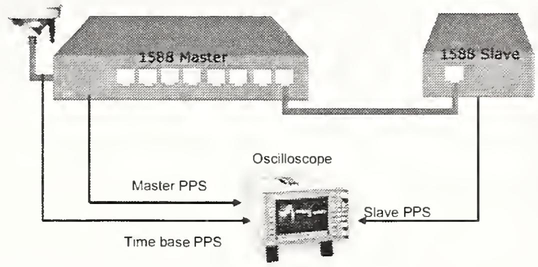
OnTime networks

Conformance Task Group

How to improve this?

4. The accuracy of synchronization between two clocks

Proposal:



A pulse per second signal (PPS) from the clock along with a specification of the latency between the PPS port and the clock.

OnTime networks

Conformance Task Group

How to improve this?

5. Bias in a clock introduced either by the servo or internal latency asymmetry

Proposal:

In addition to the PPS signal, visibility of the timestamps used by slave servos as inputs: i.e. slave received SYNC timestamp and slave receive precision SYNC timestamp contained in the FOLLOW_UP message from the master as well as the corresponding timestamps for the DEL_REQ. This can be via a new management message or perhaps a callback.

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Conformance Task Group

How to improve this?

Also:

Serious consideration should be given to providing the information above that is derived from management messages from an alternate channel in addition to or instead of the network connection.

OnTime networks

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Conformance Task Group

Proposal for user group tasks:

- Indentify and select IEEE1588 test houses

OnTime networks

A Proposal to Open a PAR Based on the Work of the IEEE 1588 Task Groups

John C. Eidson

Outline

- Summary of task force activity
- Issues in opening a PAR
- PAR proposal
- Review of IEEE standards process
- Questions

Summary of Task Force Activity

- 3 task forces were created at the request of attendees at the 2003 IEEE 1588 conference
- You have heard the report from each
- The members of these task forces recommend that a PAR be opened.
- We will ask for your views during the open discussion session tomorrow.

Issues in Opening a PAR

The standard was published in November 2002.

- The IEEE requires reballoting every 5 years.
- Has there been enough experience since 2002 to warrant revision/extension?
- Are there compelling new application areas that need to be considered?
- Is the scope of the proposed revision appropriate and doable in a reasonable time?
- Are there a sufficient number of technically competent people willing and able to serve on a standards committee to ensure success?

PAR Proposal

The following are the PAR recommend topics: (and comments)

1. Resolution of known errors: A list of these and recommended solutions is posted on the IEEE 1588 web site. These are not expected to have appreciable impact on existing implementations.
2. Conformance enhancements: 1 PPS or equivalent signal, management message or extension fields to make internal time stamps visible.

3. Enhancements for increased resolution and accuracy: Extension fields to allow sub-nanosecond time stamps, shorter sync_intervals allowed.
4. Increased system management capability: Additional management messages, perhaps SNMP
5. Mapping to DeviceNet: Few if any changes required in body of standard

6. Annex D modifications for variable Ethernet headers: Likely additions are tagged frames and IPV6. These could impact existing packet recognition designs and protocol stacks.
7. Prevention of error accumulation in cascaded topologies: New clock type (transparent clock), topology and system design guidelines.
8. Ethernet layer 2 mapping: Possible optional shorter frame, shorter sync_interval. Must resolve needs of industrial and telecommunication applications.

9. Extensions to enable implementation of redundant systems: Two independent concerns- master clock failure and network failure. Additional management or other hooks- force recomputation of delays/topology…, use of alternate domains, … This is the most uncertain of the possible areas as far as impact.
10. Extension mechanism: Uniform way of extending fields/messages.

PAR Proposal Topics Summary

1. Resolution of known errors
2. Conformance enhancements
3. Enhancements for increased resolution and accuracy
4. Increased system management capability
5. Mapping to DeviceNet
6. Annex D modifications for variable Ethernet headers
7. Prevention of error accumulation in cascaded topologies
8. Ethernet layer 2 mapping, small frame, shorter sync_interval
9. Extensions to enable implementation of redundant systems
10. Extension mechanism

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Review of IEEE Standards Process

1. IEEE sponsor (Kang Lee for TC-9 of I&M Society) appoints chair of working group.
2. Solicit membership in working group.
3. Draft and submit PAR (project authorization request) to the IEEE
4. PAR approval (earliest possible date February 4, 2005)
5. Develop revised standard (12-18 months)
6. Submit to IEEE ballot process (~ 3 months)
7. Revise/re-ballot if necessary
8. Editorial/publish process with IEEE (~ 3 months)

2004 Conference on IEEE 1588

Questions?

2004 Conference on IEEE 1588

A Proposal to Create a Trade Association to Promote IEEE 1588 Technology

John C. Eidson

Outline

- Background
- Example of trade associations & activities
- Issues relative to IEEE 1588 technology
- Straw man invitation
- Next steps
- Questions

Background

- We have received several requests to investigate forming an IEEE 1588 trade association.
- We have heard varying reactions to this idea.
- During the open discussion session tomorrow we want to hear your views.

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Background

- Standards organizations, and the IEEE in particular, almost never:
  - Certify conformance or interoperability
  - Conduct trade promotion activities

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Example of Trade Associations & Activities

Typical trade associations goals or objectives:

1. Legal: trademark, licensing, policy, …
2. Marketing: product catalog, conferences, trade shows, publications, web sites
3. Interoperability: certification, technical working groups, training, standards activity

Typical organizations have a small professional staff with much of the work, including the board of directors, done by volunteers from member companies.

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Example of Trade Associations & Activities

Typical trade associations:

•ODVA

•Profibus International

•ISA

•WiFi Alliance

•MEF

•IVI Foundation

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Issues Relative to IEEE 1588 Technology

- IEEE 1588 application areas are broader than relevant existing trade associations
- Conformance and interoperability of products targeted at multiple areas
- Marketing: Coordinate this conference?, publicity, web site,…
- Technical
  - Relationship with IEEE:
  - Direction of the technology
  - Interim trials of new mappings, etc. prior to standardization
  - Leadership pool for standards work

Straw Man Invitation

Your company is invited to send a representative to a kick-off meeting to explore the desirability, scope and organization of a trade association of companies and organizations involved with IEEE 1588 technology. The meeting will be held at TBD on TBD.

The proposed association would be a legal entity composed of dues paying member organizations and companies. There would be a board of directors governing the operation of the association. The proposed responsibilities of the association are:

• Promotion of IEEE 1588 technology (web site, conference support, trade publications, leadership pool,…),

•Promotion of interoperability among IEEE 1588 devices (establishing conformance tests and testing, plug-fest, possibly trademarks…),

•Cooperation with other related associations and standards setting bodies.

Next Steps

Depending on your comments in the open discussion session tomorrow we will:

•Do nothing

OR

•Request each of you to send us the name of the appropriate person in your organization to receive an invitation to an exploratory meeting

•Solicit a few people to sponsor, coordinate, and run the initial exploratory meeting

•The rest would depend decisions made by those attending the initial meeting.

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Questions?

2004 Conference on IEEE 1588

Plug Fest Report

A. Moldovansky
Rockwell Automation

Plug Fest Goal

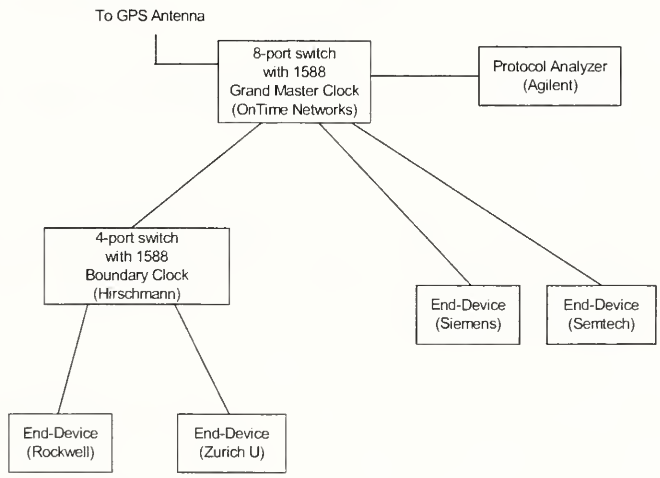
Demonstrate interoperability of system-wide clock synchronization using the IEEE 1588 across a wide spectrum of devices from various manufacturers.

Participants

- Agilent Technologies
- Hirschmann Electronics
- OnTime Networks
- Rockwell Automation
- Semtech Corporation
- Siemens AG, Automation and Drives
- Zurich University of Applied Sciences, Winterthur

2004 Plug Fest 3

IEEE 1588 Plug Fest Network



2004 Plug Fest 4

Test Conditions

- All nodes on the Plug Fest network will operate on data rate of 100Mbps and in the full duplex mode.
- All nodes will support the Synch packet interval of 2 seconds (default).
- All nodes should support the 1PPS output.

Results

- Devices were able to synchronize with each other.
- Accuracy of synchronization is in the range between 20-50ns to 200-300ns depending on implementation.

IEEE 1588 over IEEE 802.11b for Synchronization of Wireless Local Area Network Nodes

Afshaneh Pakdaman and Todor Cooklev,
San Francisco State University
John Eidson, Agilent Technologies

afshan@sfsu.edu

Overview

Introduction

- IEEE 1588
- IEEE 802.11b
- IEEE 1588 Clock Synchronization over IEEE 802.11b Wireless Local Area Network
- Conclusions
- Future work

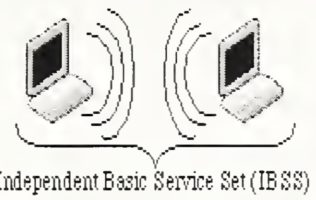
LAN (Local Area Network)

- A computer network that spans a relatively small area. There are many different types of LANs. Ethernets being the most common for PCs.
- IEEE 1588 is a new standard for precise clock synchronization for networked measurement and control systems in the LAN environment.
- IEEE 1588 has sub microsecond accuracy.

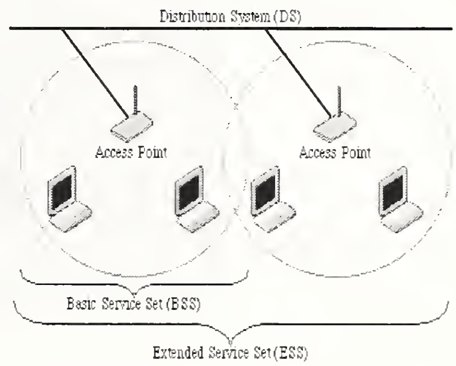
Wireless LANs

- A wireless local area network (WLAN) uses radio frequency (RF) technology to transmit and receive data over the air. The IEEE has established the IEEE 802.11 standard.
- Wireless LANs (WLAN) are increasingly used to extend wired networks due to easier installation and freedom of movement.

Topologies in Wireless LAN



Wireless Ad Hoc Mode

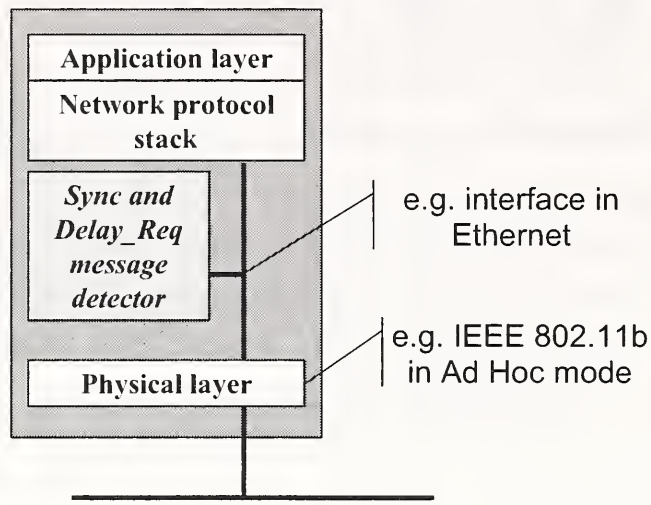


Wireless Infrastructure Mode

IEEE 1588 Timing Related Messages

- Four types of timing messages: Sync, Follow_Up, Delay_Req, Delay_Resp
- Issuing and response to these messages dependent on the ‘state’ of each clock
- The Sync and Delay_Req messages are time stamped when they sent and received

Detection of Sync messages



IEEE 802.11b Standard

- PHY layer
- MAC Layer

PHY and MAC layer

- Data shall be exchanged between the MAC and the PHY by series of PHY-DATA requests issues by MAC and PHY-DATA. confirm primitives issued by PHY.

At the Master node:

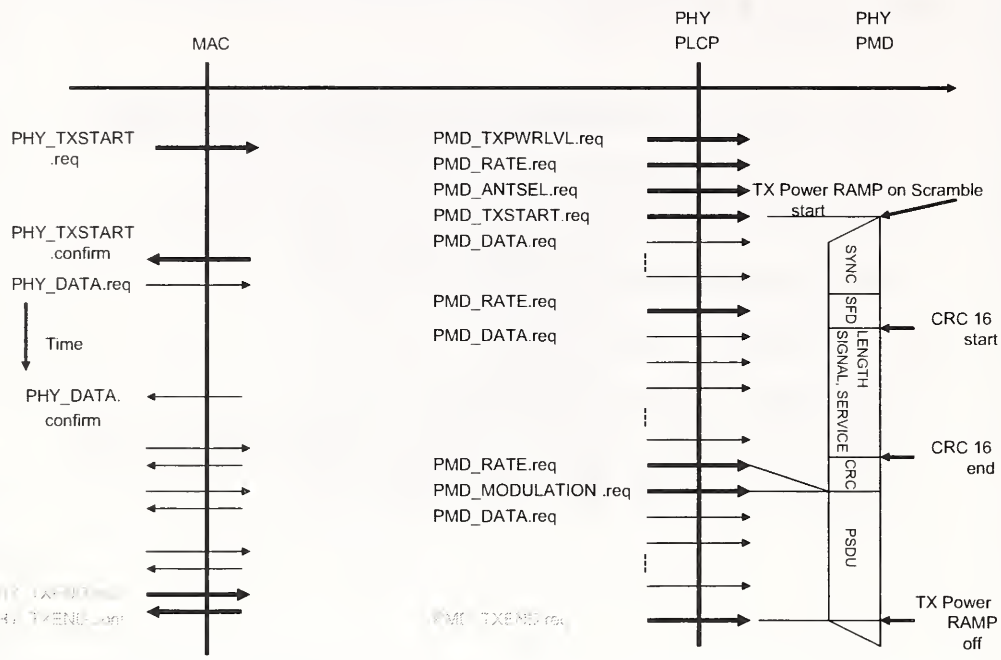
- The PHY layer indicated Last_Symbol_on_Air event to the MAC layer using PHY-TXEND.confirm.

PHY and MAC layer (continued)

At the slave node:

- The PHY layer indicates the Last_Symbol_On_Air event to the MAC layer using the PHY_RXEND. indication primitive.

PLCP Transmit Procedure



Mapping IEEE 1588 over 802.11b

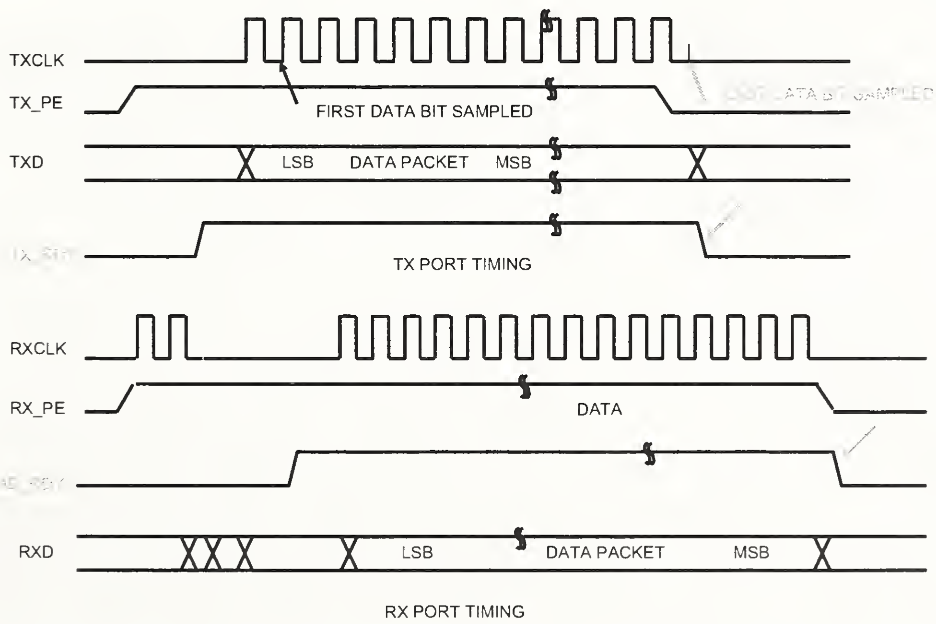
Delay Spreading:

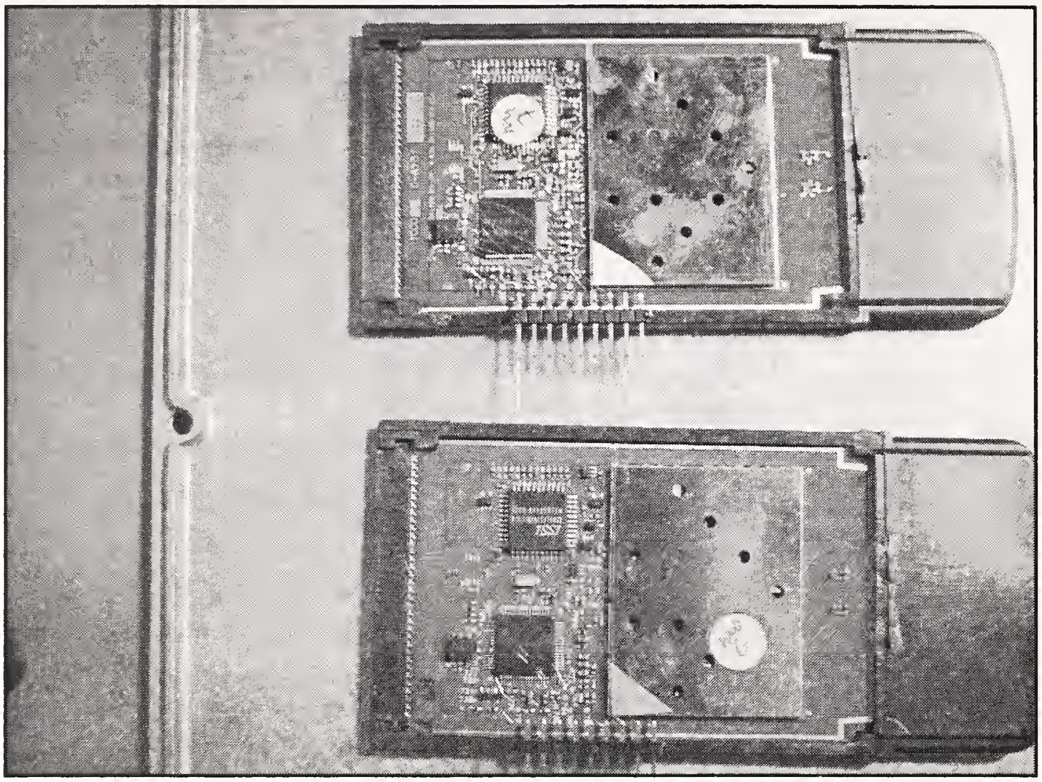
- It is associated with multipath signal.
- Processing Delay
- Jitter between the Transmitter and Receiver devices

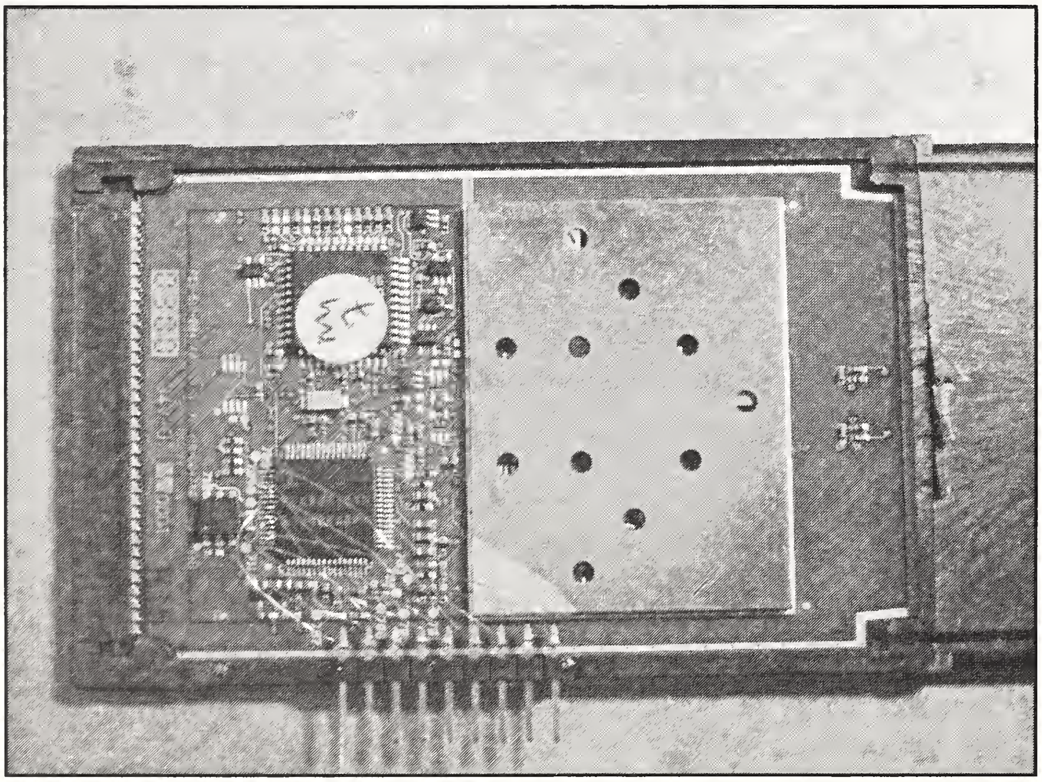
Mapping IEEE 1588 over 802.11b (continued)

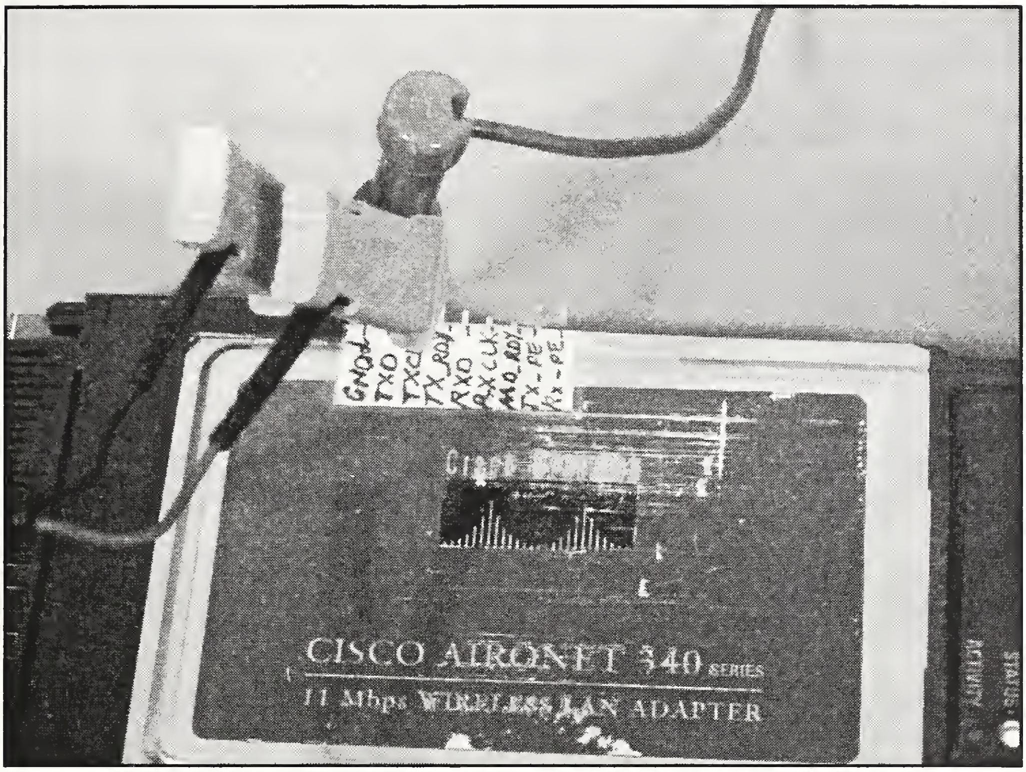
- Time stamp point
- Last_Symbol_on_Air
- This indication is observable by all the stations.
- It is readily available from the PHY layer in the form of either PHY_RXEND indication or PHY_TXEND indication.

Timing Diagram

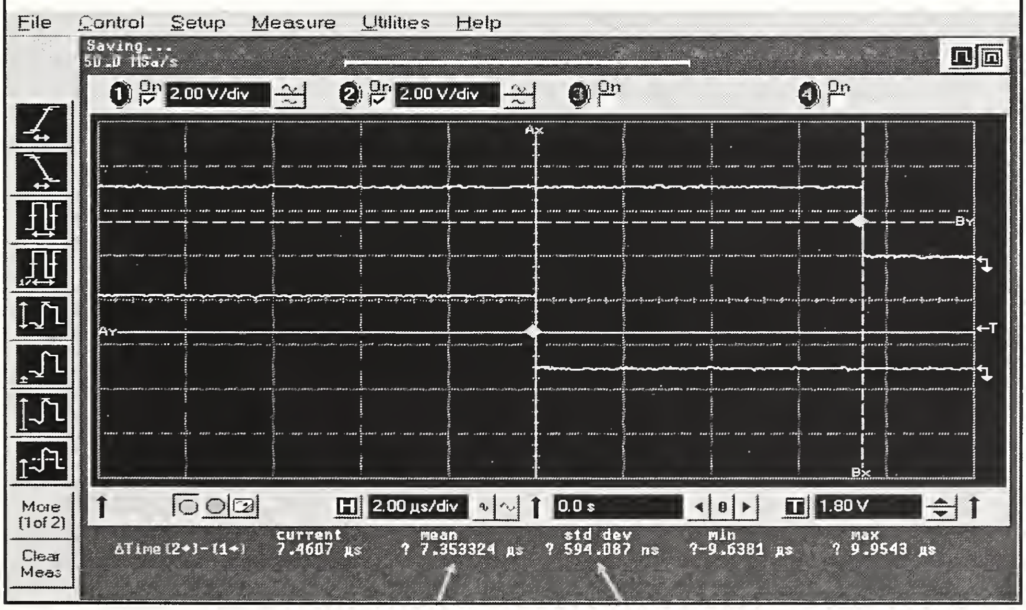




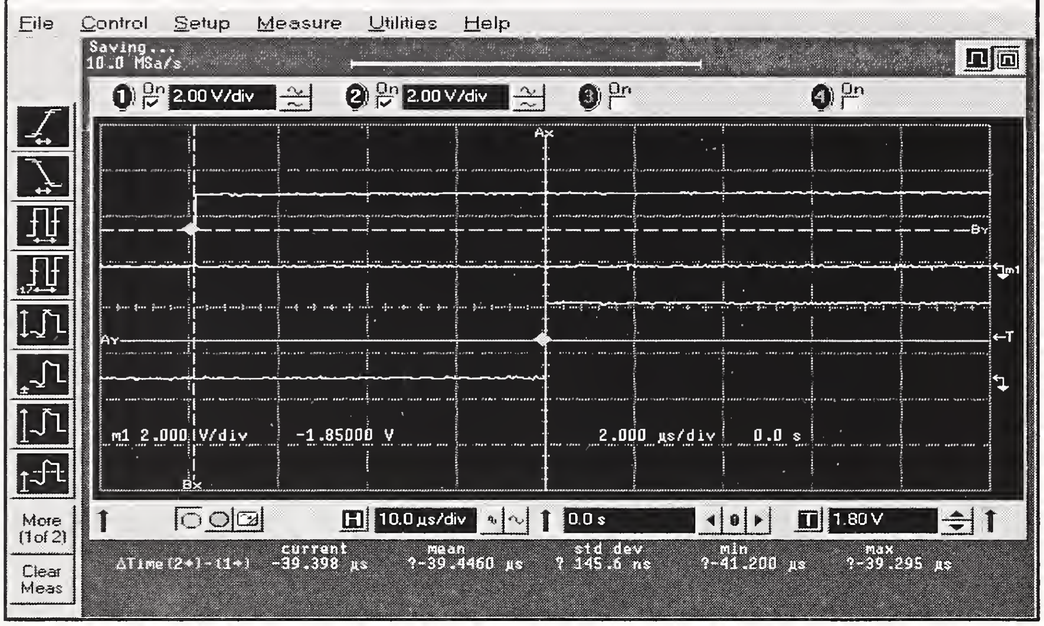




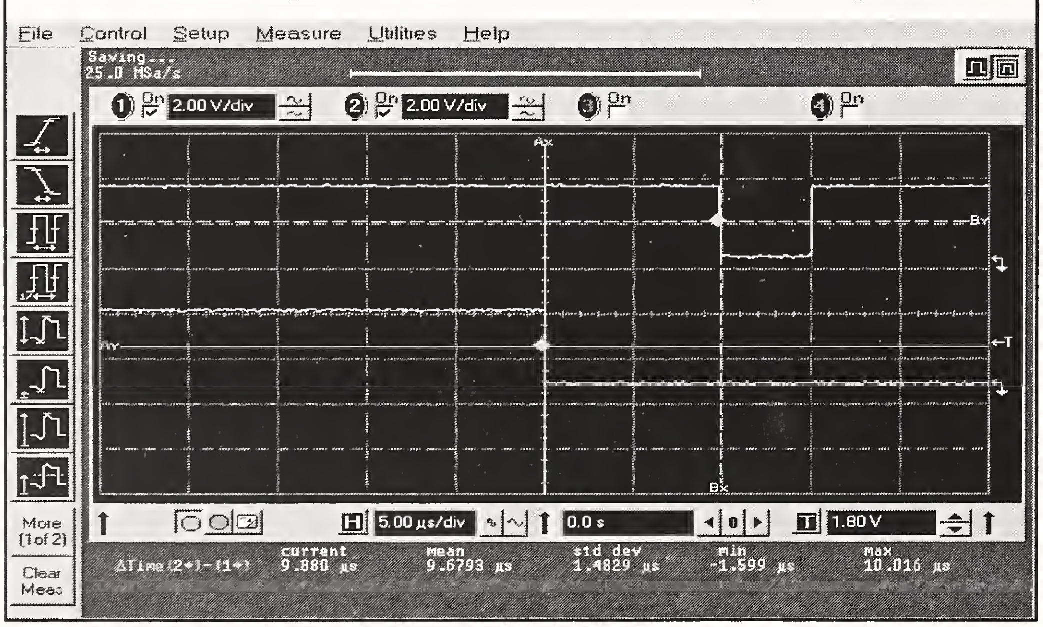
Time interval between TX_RDY on Device A and MD_RDY on Device B falling edge

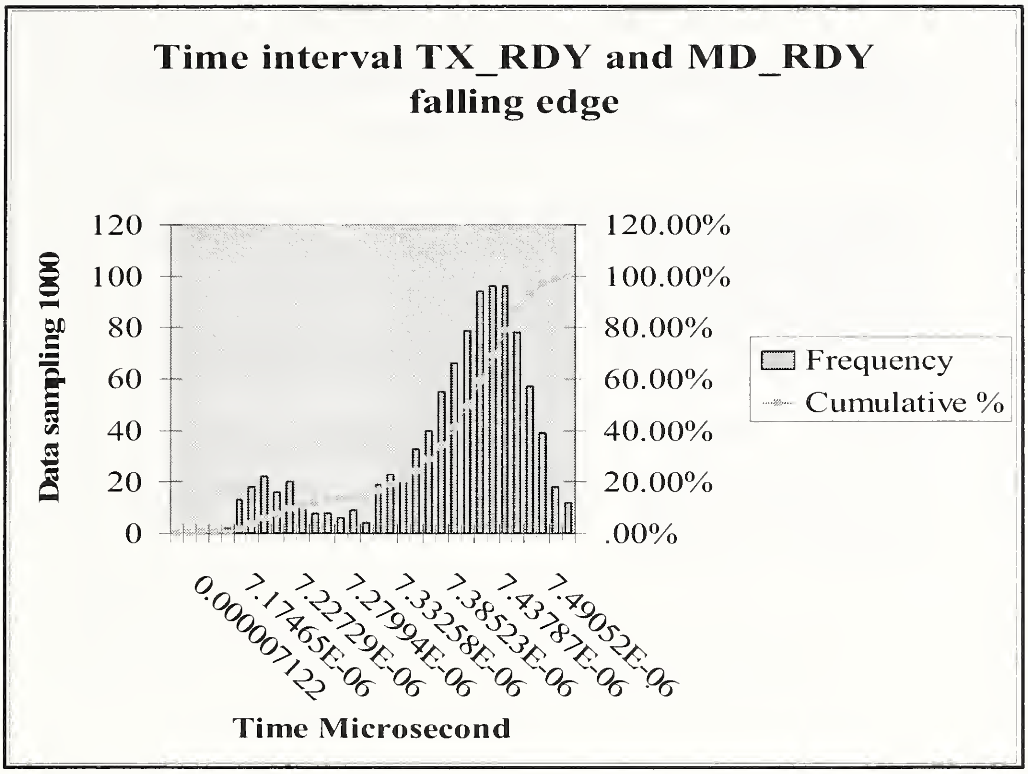


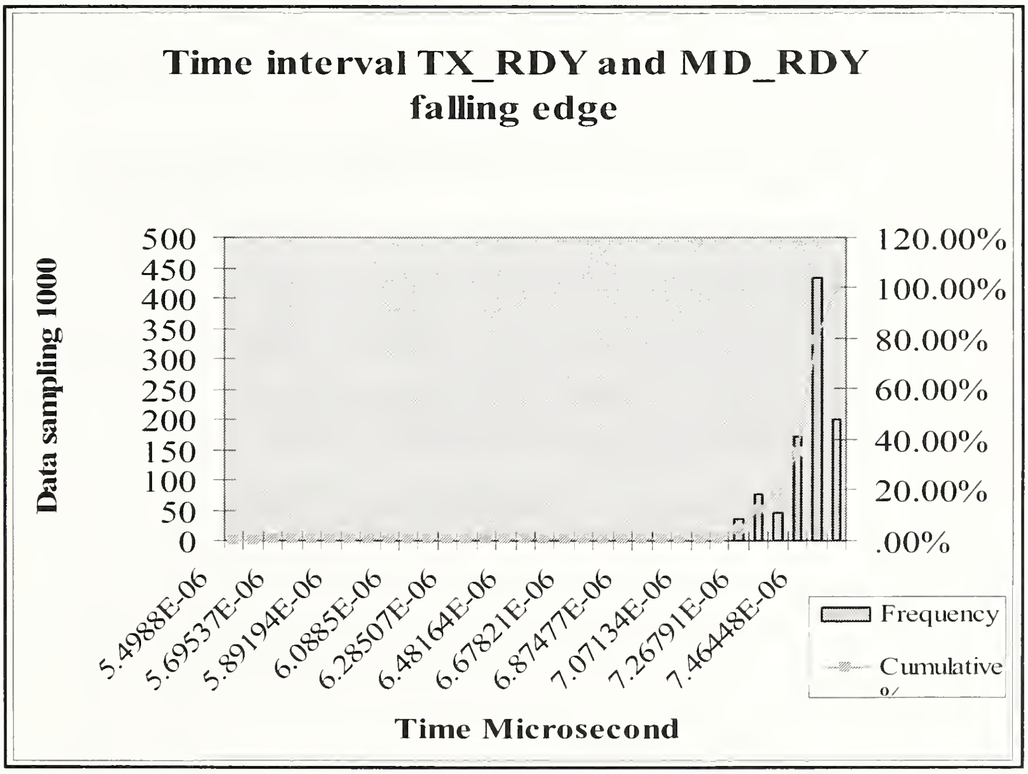
Time interval between TX_RDY on Device A and MD_RDY on Device B rising edge



Time interval between TX_PE on Device A and RX_PE on Device B falling edge




Time interval TX_RDY and MD_RDY falling edge
120
100
80
60
40
20
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
.00%
Data sampling 1000
Frequency
Cumulative %
0.000007122
7.17465E-06
7.22729E-06
7.27994E-06
7.33258E-06
7.38523E-06
7.43787E-06
7.49052E-06
Time Microsecond


Time interval TX_RDY and MD_RDY falling edge
500
450
400
350
300
250
200
150
100
50
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
.00%
Data sampling 1000
5.4988E-06
5.69537E-06
5.89194E-06
6.0885E-06
6.28507E-06
6.48164E-06
6.67821E-06
6.87477E-06
7.07134E-06
7.26791E-06
7.46448E-06
Frequency
Cumulative
Time Microsecond

Conclusions

- State the meaning of the results in terms of synchronization, IEEE 1588 can be implemented over WLAN.
- TX_RDY and MD_RDY Falling edge looks best for implementing IEEE 1588.
- PHY jitter is 500 to 600 ns and the average offset is 7.35 us.

Future work

- Adding an annex to IEEE 1588 standard for Wireless Local Area Network implementation of PTP (precise time protocol).
- Design the hardware assist circuits that permit IEEE 1588 to achieve sub-microsecond synchronization for WLAN.

High Accuracy Clock Synchronization Using IEEE 1588

Pritam Baruah, Jeff Burch, Pruthvi Chaudhari, Paul Corredoura, John C. Eidson, Andrew Fernandez, Bruce Hamilton, John Stratton, Dieter Vook

Agilent Technologies

Outline

- **Motivation for this work**
- **Practical issues in achieving nanosecond level synchronization**
- **Experimental results**

Why would anyone want to sync to 1 ns?

Instrumentation and testing of high speed systems:

•Electromagnetic signals propagate at ~1 foot/ns

•Network signaling rates in GHz range with packet dimensions in low ns range

Agilent Labs Project Goals

Extend IEEE 1588 using

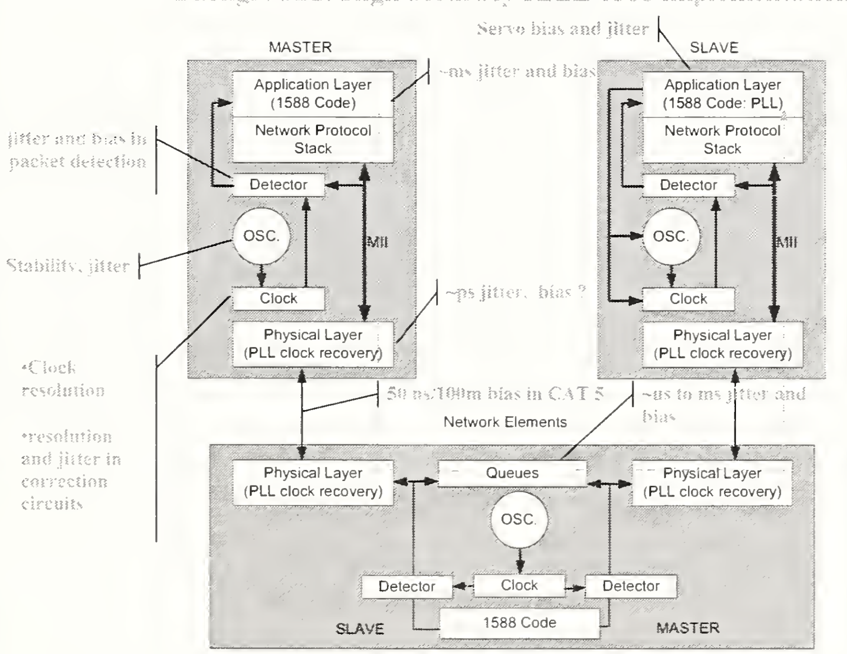
- More stable oscillators
- 100BT or Gigabit-Ethernet
- Increased bit resolution of clocks

Build demonstration version

Practical issues in achieving nanosecond level synchronization

- **Background**
- **Oscillator characteristics**
- **Clock resolution**
- **Network signaling characteristics**
- **Topology**

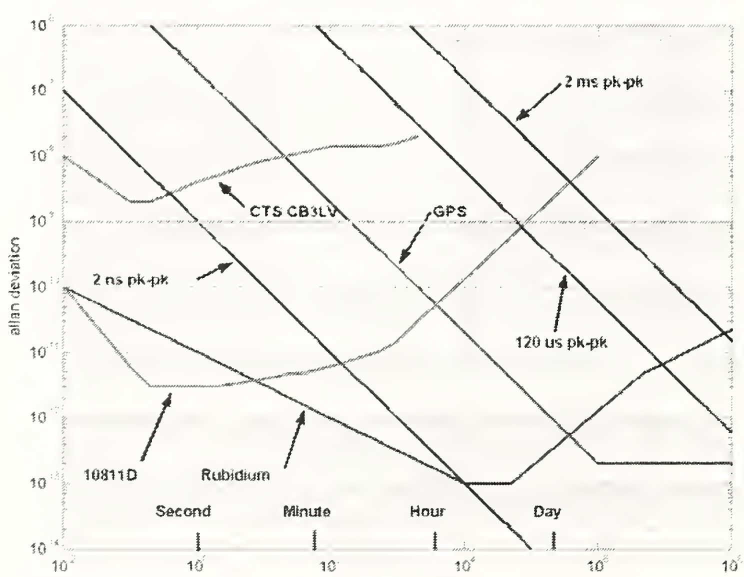
Background: High accuracy IEEE 1588 implementation



Thermal considerations

- Oscillator drift is a major contributor to synchronization errors.
- Quartz crystal based oscillators
  - Uncompensated oscillators generally in few ppm/degree range
  - Thermal compensation typically x10 to x100 better
- Atomic based oscillators
  - Several orders of magnitude less drift than quartz

Oscillators: Allan Deviations for Common Sources



Clock resolution considerations

- The LSB of the actual clock and any datatype representation limits measurement and therefore synchronization accuracy
- The minimal rate and/or offset adjustment of the clock and any datatype representation limits the ability of the servo to correct to the desired accuracy.

Network signaling characteristics

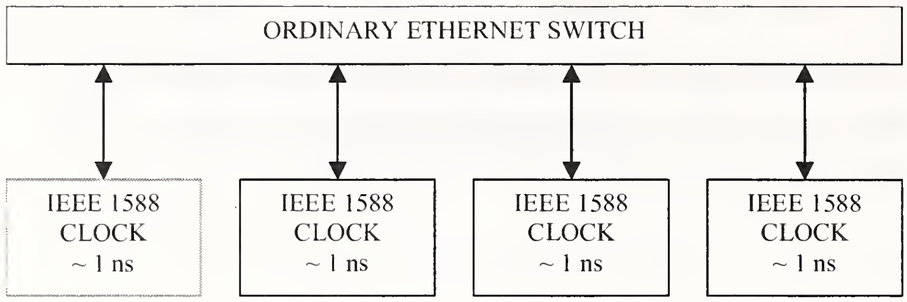
Signaling rates:

- 10 BT: 10 MHz, 100 ns period
- 100 BT: 25 MHz, 40 ns period
- 1000 BT: 125 MHz, 8 ns period

Rise time of the network signal limits the accuracy of generating a reproducible time stamp

Accuracy Issues (topology)

Single subnet: switch jitter a problem at ns level



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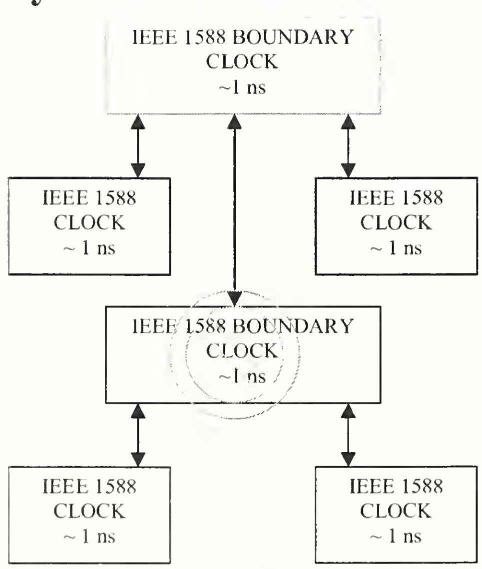
Accuracy Issues (topology)

Hierarchy: Error accumulation at ns level



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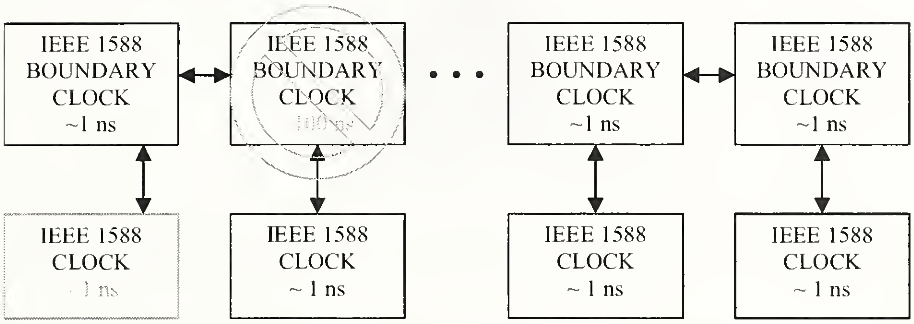
Accuracy Issues (topology)

Linear: not currently feasible at ns levels

1. **Cascaded devices accumulate servo error & quantization errors a severe problem at ns level**
2. **Low accuracy intermediate devices dominate error budget of chain**



Accuracy Issues (asymmetry)

1. **Path asymmetry introduces offset errors significant at ns level**
2. **The major source of asymmetry in a complex network is queuing differences in switches/routers or in actual routing differences.**
   - **At ns level probably rules out all but single level hierarchy, i.e. direct master boundary clock to slave**
3. **Physical media can also be asymmetric**
   - **CAT5 cable asymmetry is nominally 25-50ns/100m**
   - **Measure and correct for delay**

Experimental results

- Clock design
- Measurements

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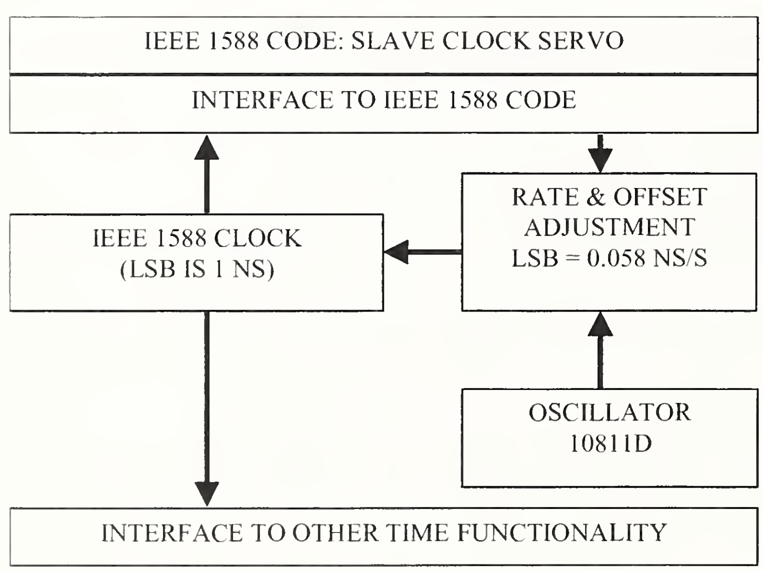
Experimental clock design



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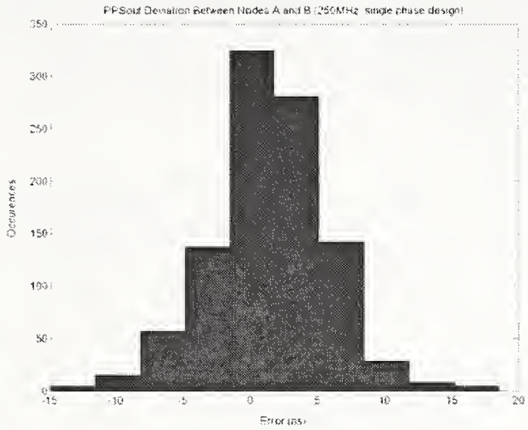
Histogram of 1 PPS deviations in directly connected clocks.



Resolution (LSB) = 4 ns. Sync interval 2 seconds. Short averaging time. Standard deviation = 4.4 ns, mean = 1.5 ns.

Next steps: 1 ns LSB, long averaging time in servo.

Primary Timing Reference Sources for IEEE-1588 Systems

Paul Myers

pmyers@spectracomcorp.com

www.spectracomcorp.com

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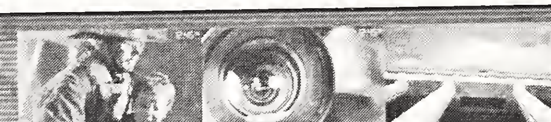
LEGALLY TRACEABLE TIME™



Master Clock Requirements

- IEEE 1588 Protocol Implementation
- Time Source
  - UTC Time Reference, or arbitrary user defined time base
  - 1 PPS or On Time Point input
  - May support an optional secondary Time Source
- Port to Physical Transport - e.g. Ethernet
- Oscillator
  - Meets minimum accuracy, stability, and adjustment range
  - Satisfies Holdover Time between max sync time interval
- 1PPS Output
- User Interface

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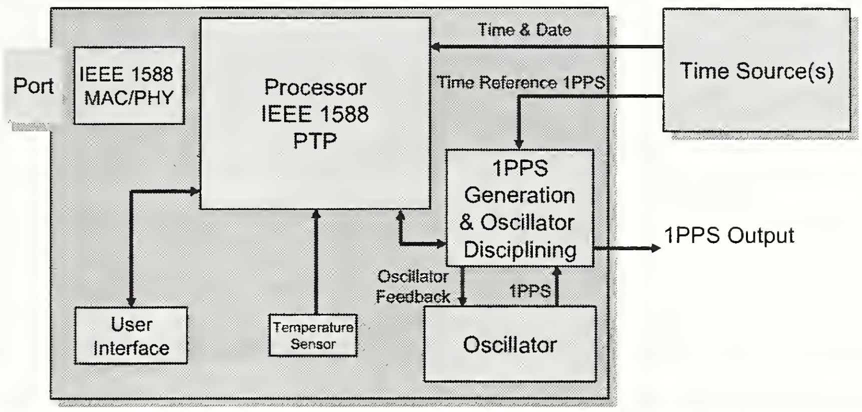
Architecture of a Master Clock



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Time Source Characteristics

- Time sources typically have two primary features
  - Delivery of current time
    - Current UTC, Local or arbitrary user defined time is delivered within a specified accuracy
  - On Time Point or 1PPS input
    - Many time delivery protocols provide a means to indicate that at a particular instant the current time data is valid. This is typically done by an On Time Point in a data stream or by a 1PPS input.

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Time Sources

- Radio Clocks
  - Radio signals
    - US – (WWV, WWVB, WWVH), Germany-DCF77, UK-MSF, Japan-JJY, Canada-CHU, .etc
  - GPS, GLONASS, India's NPL INSAT
  - Loran, Enhanced Loran
  - Cellular Networks - GSM, CDMA
- Terrestrial Time Servers
  - Private and Public NTP Servers
  - NIST Services Dial Up (ACTS), Internet (ITS), and FMS
- External Interface to a Time Source
  - IRIG, RS-232, RS-422, RS-485, and E1/T1 (SDH)

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Radio Signals as a Time Source

- Benefits
  - Supported by National Labs and Standards bodies
  - Broadcast is generally available across wide area
  - Antenna and sky view only is required
  - Typically has good long term stability/accuracy
- Drawback
  - Regionally available
  - Reception can vary due to atmospheric conditions and interference
  - Indoor reception can be difficult or poor
  - Radio Receiver for Time Source signals can be low cost or expensive for full NTP Time Server systems

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GPS as a Time Source

- Benefits
  - GPS receiver cost is dropping and sensitivity increasing
  - Typical GPS Receiver is a very accurate/stable time source
  - Acts as a reference to an Atomic Clock Standard
  - Available worldwide
- Drawbacks
  - Dependent on US Military
    - Reception can be jammed & degraded
  - Antennas must have clear sky-view, doesn't work indoors
  - Not all GPS receivers are suitable for time sync
    - Poor stability and/or accuracy
    - Not all GPS receivers provide 1PPS

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Loran as a Time Source

- Benefits
  - Available across large areas of land and sea
  - Accuracy and stability is similar to GPS
  - Ground wave signal is stable and easy to receive
  - Referenced to Atomic Clocks
  - Metrics and phase data available daily
- Drawbacks
  - Equipment cost can be higher than GPS systems
  - Reception is limited geographically
  - Long term future of Loran system is uncertain

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GSM and CDMA as Time Sources

- Benefits
  - Typically slaved to GPS
  - Available anywhere GSM/CDMA reception works
  - Indoor reception possible
  - Provides a data link connection if needed
  - About the same cost as a GPS based solution
- Drawbacks
  - GSM and CDMA are only regionally available
  - Not all Cellular networks are synced to UTC
  - Does not provide a GPS independent backup
  - May not provide 1PPS input

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NIST and NTP as Time Sources

- Benefits
  - Dial up and Internet NTP Servers are maintained by National Standards bodies
  - Reliable Modem backup to Internet and GPS
  - Low cost
- Drawbacks
  - Not as accurate as other sources
  - Subject to internet and telephony access risks
  - No 1PPS input for modem and internet interfaces

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External Interfaces to Time Sources

- Benefits
  - Provides direct 'foreign' connection to external time source such as
    - Atomic Clock, GPS, Radio, GSM/CDMA, NTP Server, Loran, .etc
  - On Time Points of protocols can simulate 1PPS
- Drawbacks
  - Inputs could lack 1PPS input or On Time Point
  - High latency of some interfaces may require a lower Stratum level than the Time Source

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What does Stratum mean?

- IEEE 1588
  - Indicates with Identifier time accuracy relative to UTC
  - Identifies whether a clock is a Primary, Secondary, or is not a Reference to a standardized source of time
- NTP
  - Stratum & Code indicate Reference status/source
    - 0 – Undefined, 1 – Primary, 2-255 – Secondary
    - Codes - e.g. NIST, ATOM, VLF, WWVB, LORC, GPS
- T1.101
  - Stratum indicates minimum accuracy of clocking
    - Stratum 1 - $<1x10^{-10}$, Stratum 2 – $<1.6x10^{-8}$, Stratum 3 - $<4.6x10^{-5}$, Stratum 4 - $<3.2x10^{-5}$

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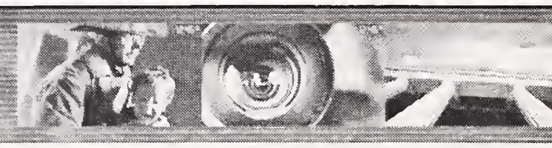

Stratum Numbers

Table 3—Stratum number definitions

Stratum number	Specification
0	May be used temporarily for special purposes by PTP implementations to force a clock to be deemed better than other clocks in the system.
1	Designates the clock as a primary reference standard traceable to a recognized standard source of time. A stratum 1 clock may be either a boundary clock or an ordinary clock. (NOTE— GPS clocks, calibrated atomic clocks, etc., fall into this stratum). A stratum 1 clock shall not be synchronized using the PTP protocol to another clock in a PTP system.
2	Designates the clock as a secondary standard reference clock. The clock shall be: — Directly (not via PTP) synchronized to a stratum 1 clock or another source deemed to be a correct source of time for the PTP subdomain or — Previously directly synchronized to a stratum 1 clock or another source deemed to be a correct source of time for the PTP subdomain and is still providing time information consistent with this clock or source as specified by the clock_identifier associated with the clock (see 6.2.4.5)
3	The lowest possible clock_stratum value if not 1 or 2 for a clock that is capable of issuing external timing signals and possibly setting the PTP_EXT_SYNC flag to TRUE (see 8.2.10)
4	The lowest possible clock_stratum value if not 1 or 2 for a clock that does not have the capability of issuing external timing signals and therefore sets the PTP_EXT_SYNC flag to FALSE (see 8.2.10).
5–254	Reserved.
255	The default value. A clock with this stratum number shall never be the best master clock.

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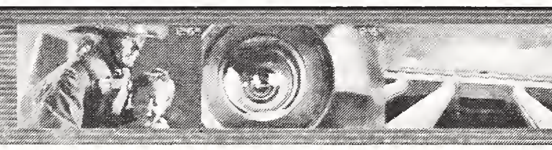

Clock Identifiers

Table 4—Clock identifier definitions

Clock identifier (ASCII)	Applicable to clock_stratum number	Specification
ATOM	1	Time is derived from a calibrated atomic clock maintaining a UTC time base accurate to better than 25 ns
GPS	1	Time is derived from a correctly operating GPS receiver maintaining a UTC time base accurate to better than 300 ns.
ATOM	2	The stability of the clock is such that it is accurate to within 100 ns of the UTC time base established the last time it was synchronized directly to a stratum 1 clock with clock_identifier ATOM. A power cycle may preclude this designation.
GPS	2	The stability of the clock is such that it is accurate to within 100 ns of the UTC time base established the last time it was synchronized directly to a stratum 1 clock with clock_identifier GPS. A power cycle may preclude this designation.
NTP	2	The clock shall meet one of the following specifications: - The clock is correctly and actively participating in a suite of clocks using the NTP or equivalent protocol to maintain a UTC time base accurate to better than 15 ms, or - The stability of the clock is such that it is consistent to within 50ms of the time base established the last time it was correctly and actively participating in a suite of clocks using the NTP or equivalent protocol to maintain time consistent with UTC A power cycle may preclude this designation. Examples of protocols providing time bases and accuracies equivalent to NTP are SNTP, link to NIST time server, etc.
HAND	2 or greater	The clock has been set to the correct UTC time to accuracy better than 10 seconds by an administrative procedure and is consistent with that time except for normal drift of this clock. A power cycle may preclude this designation.
INIT	2 or greater	The clock has been set with unspecified accuracy to an arbitrary or user-defined time by an administrative procedure and is consistent with that time except for normal drift of this clock. A power cycle may preclude this designation.
DFLT	3 or greater	Applicable if none of the other clock_identifiers apply.

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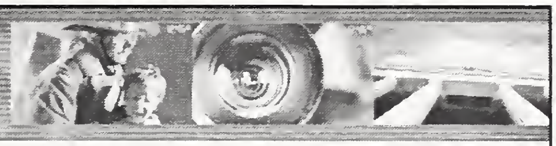

Stratum Levels and Clock Identifiers

Identifier	Stratum	Specification	Time Source
ATOM	1	< 25 ns	UTC Atomic Clock
GPS	1	< 100 ns	GPS Receiver
ATOM	2	<100 ns	UTC Atomic Clock
GPS	2	< 100 ns	GPS Receiver
NTP	2	< 15 msec	NTP Server - Internet
NTP	2	< 50 msec	NTP Server - Dialup
HAND	>= 2	< 10 sec	Setting time manually, or automated
INIT	>= 2	Unspecified	User Defined
DFLT	>= 3	None	None

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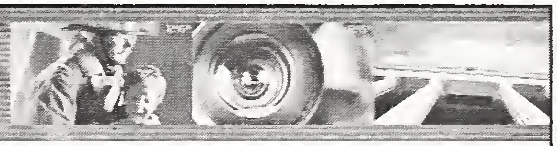

Stratum Levels and Clock Identifiers

Time Source	1PPS - Time Uncertainty	Frequency Uncertainty	Identifier	Stratum
Typical GPS Receiver	< 20 nsec	$< 1x10^{-12}$	GPS	1
GLONASS (and GPS)	20-500 nsec	10^{-9} to 10^{-13}	GPS	>= 1
INSAT	20 usec	$5x10^{-10}$	NTP	2
Loran, Enhanced Loran	<100 nsec	$1x10^{-12}$	GPS	>= 1
CDMA slaved to GPS	<10-100 usec	~GPS	NTP	2
GSM slaved to GPS	< 100 usec	~GPS	NTP	2
AMPS (Analog Cellular)	T1 or Local Clock	$\sim 1x10^{-9}$	>= INIT	>= 2
Un-synced Cellular Network	Undefined	Unknown	INIT	>= 2

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Stratum Levels and Clock Identifiers

Time Source	1PPS - Time Uncertainty	Frequency Uncertainty	Identifier	Stratum
WWVB, DCF77	0.1-15 msec	10^{-10} to 10^{-12}	NTP	2
WWV, WWVH	1-20msec	10^{-6} to 10^{-9}	NTP	2
CHU (no path delay)	< 1 msec	< 10^{-4} sec	NTP	2
IRIG	20 - 200 usec	Varies	NTP	2
RS-232, RS-485	< 0.1 - 1 msec	Varies	NTP	2
T1.101 Stratum 1-4	See Stratum	3.2×10^{-5} to 1×10^{-11}	NTP	>= 2
NIST ACTS	< 15 msec	NA	>= NTP	2
NIST ITS	< 100 msec	NA	>= NTP	>= 2
NIST FMS	< 20 nsec	2×10^{-13} to 2×10^{-15}	ATOM	1

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Oscillator Choices

- Quartz Crystals
  - Improvements include disciplined and temperature compensated crystals and PICO Ensembles of Quartz Oscillators nearing atomic clock performance
- TCXO
  - Improvements include Disciplined TCXO systems
- OCXO
  - Improvements include Disciplined OCXO systems
  - Sophisticated OCXO approaching Atomic clock performance
- Atomic
  - Rubidium, Cesium, Hydrogen-Maser

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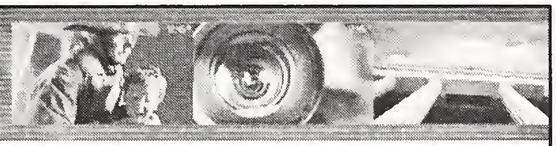

Why is Holdover important?

Holdover

- The.ability of a synchronized IEEE 1588 clock to stay within it's specification for Stratum and Identifier until the next synchronization message from it's master clock or time source
  - Defines the maximum time until a Master Clock must lower it's Stratum and Identifier if not receiving a sync from it's time source(s)
  - Holdover requirements define accuracy requirements for clock's oscillator
  - Determines Quality of Service from a Master Clock in cases of loss of time reference

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Stratum Level versus Oscillators

Oscillator	Frequency Uncertainty	Identifier	Stratum	Error Offset to UTC	Holdover
Cesium	$<1\times10^{-12} - 1\times10^{-13}$	ATOM	1	< 25 nsec	6.94 – 69.4 hours
Cesium	$<1\times10^{-12} - 1\times10^{-13}$	ATOM	2	< 100 nsec	27.78 – 277.8 hours
Rubidium	1×10^{-12}	ATOM	1	< 25 nsec	6.94 hours
Rubidium	1×10^{-12}	ATOM	2	< 100 nsec	27.78 hours
OCXO	$1\times10^{-8} - 1\times10^{-10}$	GPS	1, 2	< 100 nsec	10 - 1000 seconds
TCXO	1×10^{-6}	GPS	1, 2	< 100 nsec	0.1 seconds

Stratum Level versus Oscillators (2)

Oscillator	Frequency Uncertainty	Identifier	Stratum	Error Offset to UTC	Holdover
OCXO	$1x10^{-8} – 1x10^{-10}$	NTP	2	< 15 msec	17.36 - 1736 days
OCXO	$1x10^{-8} – 1x10^{-10}$	NTP	2	< 50 msec	57.87 - 5787 days
TCXO	$1x10^{-6}$	NTP	2	< 15 msec	4.17 hours
TCXO	$1x10^{-6}$	NTP	2	< 50 msec	13.9 hours
Quartz	$1x10^{-4} – 1x10^{-5}$	NTP	2	< 15 msec	2.5 – 25 seconds
Quartz	$1x10^{-4} – 1x10^{-5}$	NTP	2	< 50 msec	8.33 – 83.3 seconds
Quartz	$1x10^{-4} – 1x10^{-5}$	Hand	>= 2	< 10 sec	1.157 – 11.57 days

Summary

- GPS Time Sources are preferred, but others like Loran and GSM/CDMA have similar precision
- Alternate Time Sources which provide 1PPS or an On Time Point in the interface are preferred
- Utilize a backup Time Source to provide redundancy and independence from GPS
- Choose secondary time source such that your system can still function as a master clock in your application
- Design Master Clocks utilizing an oscillator with properties sufficient for your precision, accuracy and holdover requirements

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Suggestions?

- Internationalization
  - might be easier if Unicode and a Language ID is used for Strings
- Clock Identifiers
  - Would more Identifiers for different time sources be useful?
- Additional Data Sets?
  - Would Time Source manufacturer & capabilities be useful?
  - Would Vendors specific datasets be useful?
  - Would listing of all time sources and priority be useful?

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*Device**Net***

adaptation of

IEEE – 1588

Ron Holl, Rockwell Automation
Dave VanGompel, Rockwell Automation

2004 Conference on IEEE 1588, September 27-29, 2004
National Institute of Standards and Technology, Gaithersburg, Maryland, USA

1

Adapting Networks to IEEE-1588

- IEEE-1588 is designed to be network independent.
- Each network that supports 1588 provides a definition within an annex of the specification as to how 1588 maps to that network.
- Current specification has one Annex for a network definition: Ethernet (UDP/IP).
- A proposal has been submitted for a DeviceNet Annex.
- A Communication Technology code has been allocated for DeviceNet (7).

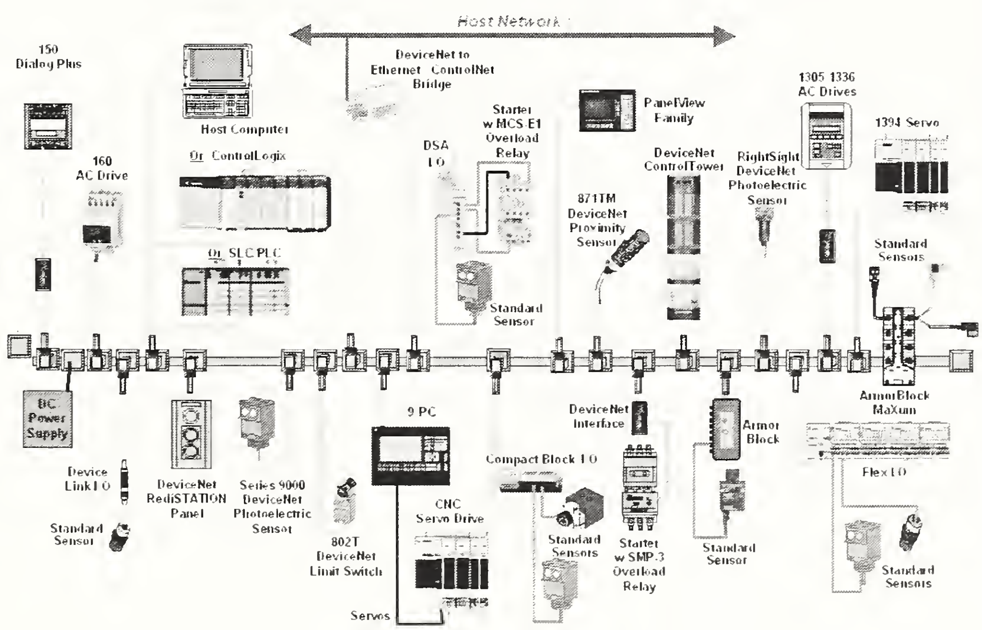
2

DeviceNet Background

- ODVA founded 1995
  - Open DeviceNet Vendor Association
  - Approx. 350 member companies around the world
- Estimated 8 million DeviceNet nodes installed
- Targeted at low end sensor and actuator devices
  - Photoeyes, limit switches, pushbuttons, bar code readers, etc
  - Motor starters, Variable Freq. Drives, pneumatic valves, etc
  - Block I/O devices
- Trunkline/dropline topology with power in the network cable for small devices (typically sensors)

3

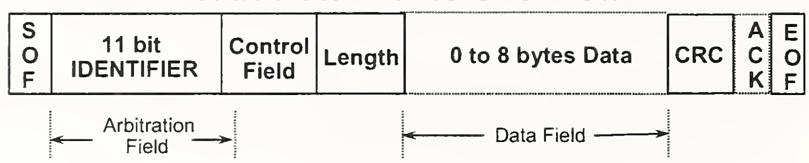
Sample DeviceNet Network



DeviceNet Data Link Layer

- DeviceNet uses CAN (Controller Area Network) technology
- The 11 bit Identifiers provide 2032 unique multicast message identifiers for the network.
- CAN does not allow more than one node to use the same Identifier.
- A CAN frame (packet) can deliver up to 8 bytes of data.

CAN Data Frame Overview



5

DeviceNet Architecture

- DeviceNet allows for up to 64 devices (nodes) on the subnet.
- Each device is assigned part of the 2032 message identifier space, where the node number of the device is part of the message identifier.
- Fragmentation is provided to allow for large messages using multiple CAN frames.
- Messages can be Unconnected, Explicit connected, or Implicit (I/O) connected.

6

DeviceNet as a Part of CIP

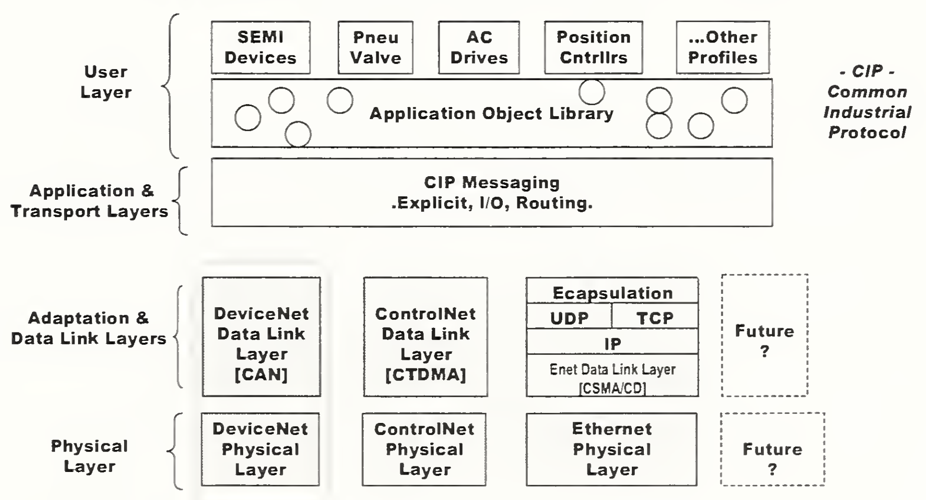
DeviceNet is one of several networks to share a common object oriented application layer called CIP.

- CIP: Common Industrial Protocol
- CIP is used by DeviceNet, ControlNet, and EtherNet/IP

ODVA is standardizing on IEEE-1588 to provide time synchronization, termed CIP Sync, for all CIP networks.

7

DeviceNet, ControlNet & EtherNet/IP Share Common Application & User Layers



8

1588/DeviceNet Adaptation

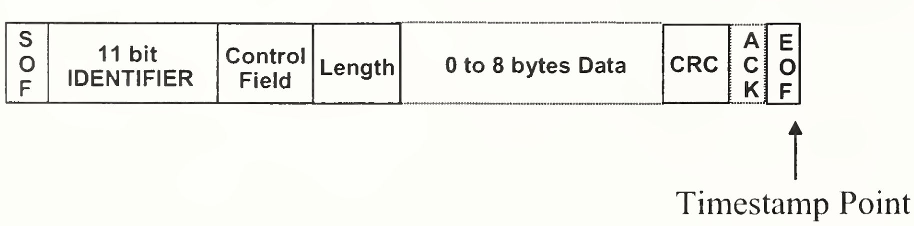
The adaptation for DeviceNet consists of:

- Selection of Message Timestamp Point
- Definition of UUID
- Mapping of 1588 Ports and Multicast Addresses
- Definition of on-the-wire format for message data

9

Message Timestamp Point

The message timestamp point shall correspond to the trailing edge of the sixth bit of the End of Frame of the first fragmented packet of a PTP message.



10

Selection of UUID

DeviceNet (along with all networks within CIP) assigns a unique 16 bit Vendor ID to each manufacturer of CIP products. In addition, every vendor assigns a unique 32 bit Serial Number to each CIP product manufactured. Thus, the CIP Vendor ID and Serial Number combination is universally unique.

Given this, the 1588 UUID (universally unique identifier) for the DeviceNet adaptation shall be the Vendor ID and Serial Number of the DeviceNet node containing the 1588 clock(s).

UUID_field = Vendor Id +
Product Serial Number +
Node Id

11

Mapping of 1588 Ports/Addresses to DeviceNet

The PTP multicast addresses shall be mapped onto the DeviceNet Unconnected (UCMM) message identifiers, with a UCMM service code uniquely identifying the combination of PTP subdomain address and PTP port.

- Each DeviceNet node has a unique message identifier on the network for sending 1588 messages.
- A total of 8 service codes are defined; one for each of two ports on each of the four subdomains.

12

Subdomain Name Mapping

To save network bandwidth, all non-management PTP messages shall use an encoded 8-bit subdomain value within the PTP header to represent the PTP subdomain name.

The mapping of names to encoded values shall be accomplished with Management messages.

1	_DFLT
2	_ALT1
3	_ALT2
4	_ALT3

13

On the Wire Data Format

- All non-management PTP messages are packed, unlike Ethernet which has 32-bit alignment.
  - sync msg = 15 frames
  - followup msg = 5 frames
- PTP Management messages are consistent with Ethernet to reduce burden and forward compatibility issues with boundary clocks (routers).
- This consistency may be extended to be the general rule for communication technologies as a separate 1588 specification update.

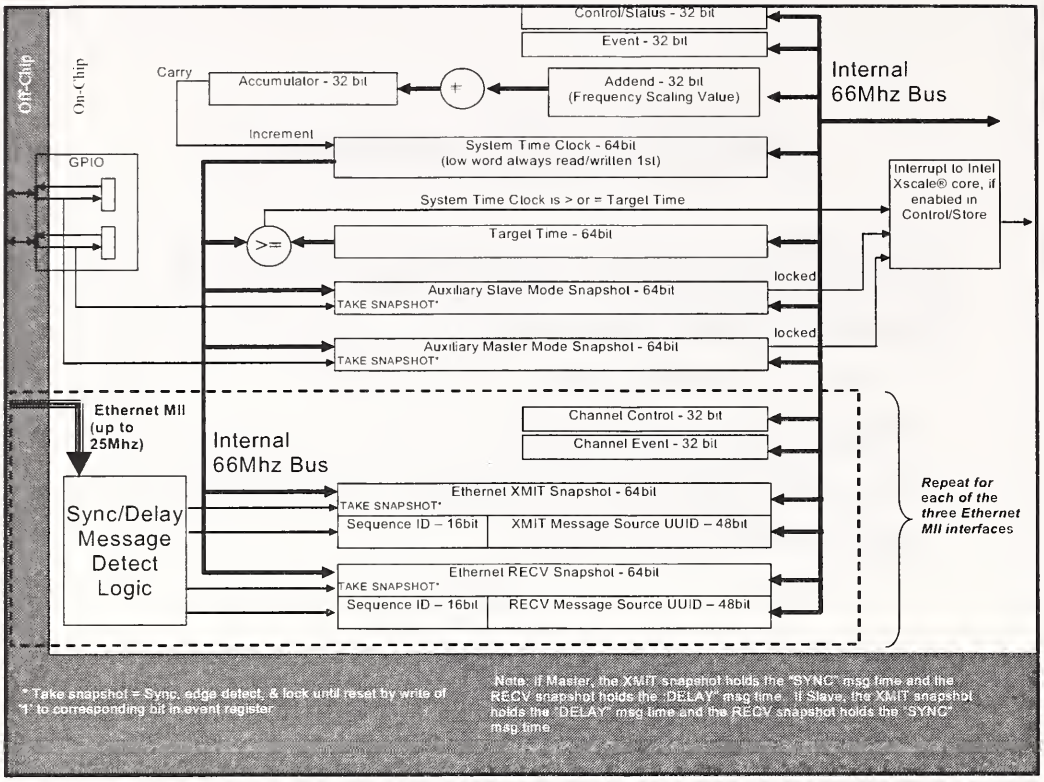
14

CIP Time Sync Object

ODVA will provide an Object definition, the CIP Time Sync Object, which will:

- Allow CIP messaging access to PTP Management messaging.
- Provide access to the 1588 time within CIP applications in the device.

15



Hardware Assisted IEEE 1588* Implementation in a Next Generation Intel® Network Processor

Puneet Sharma
Infrastructure Processor Division
Intel Corporation

Outline

- IEEE 1588* Solution in an Intel® Network Processor
- Detailed look at the IEEE 1588 Hardware Logic
- The Clock Synchronization Algorithm
- Summary

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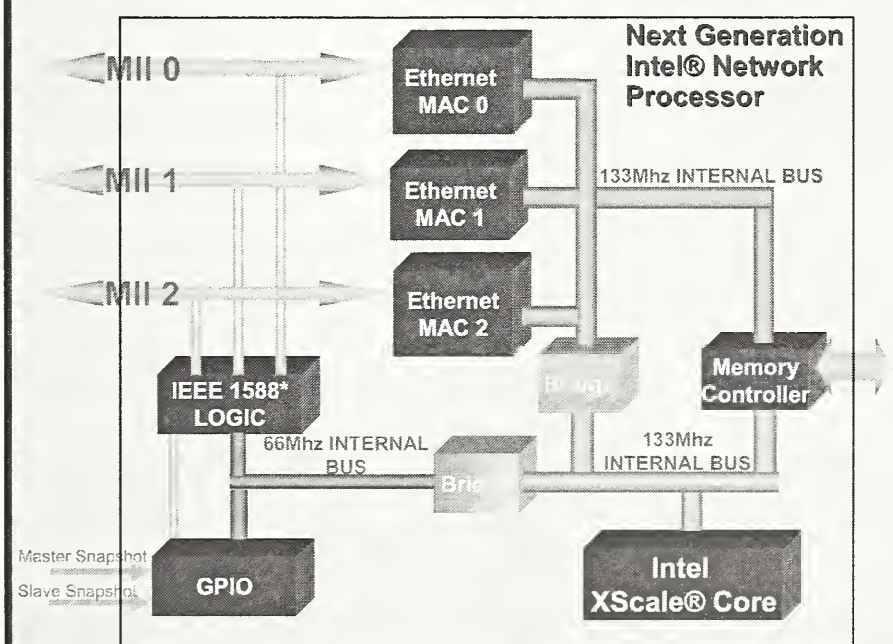

*Other names and brands may be claimed as the property of others.

IEEE 1588* Solution in an Intel® Network Processor

- Integrated Hardware Assistance to Provide the Most Accurate Timestamp
- Three MII only Interfaces Supported
- One Auxiliary Interface via GPIO inputs
- Each Interface can be Configured in Master or Slave modes of Operation.
- Intel XScale® Core Clock Synchronization Algorithm
- Intel XScale Core may Implement Any Feature Set of the IEEE 1588 Specification.
- Helps to Save on Bill of Materials (BOM) and PCB Area.

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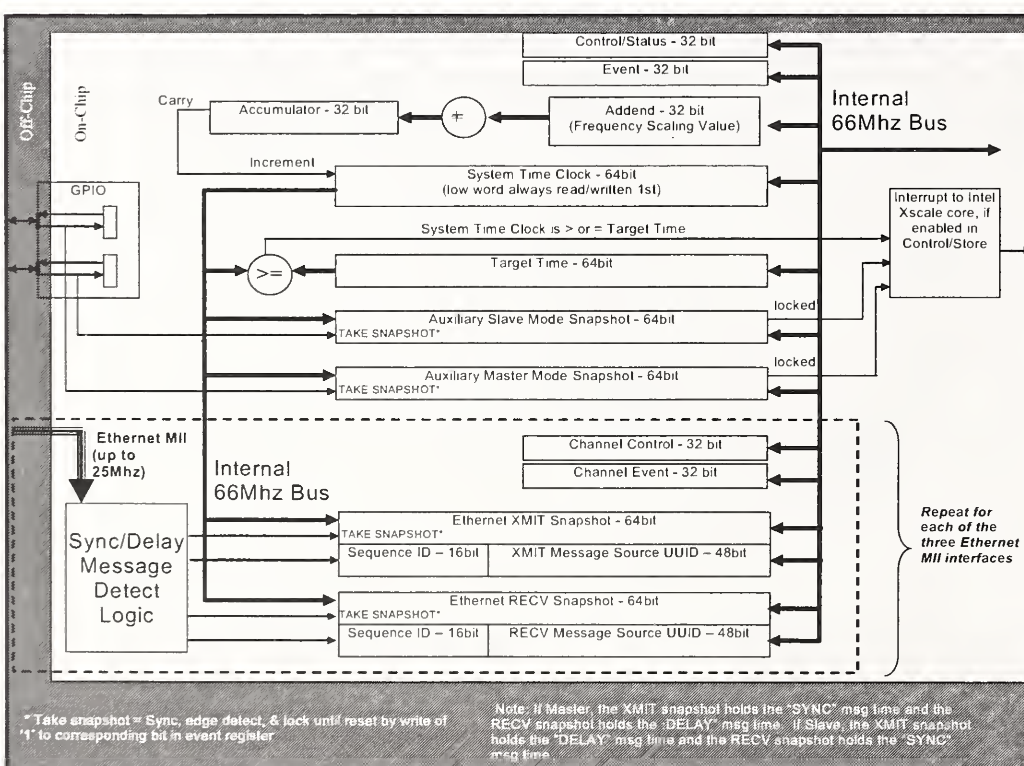

IEEE 1588* Hardware Logic Features of the Intel® Network Processor

- Logic run off of 66Mhz source clock for up to 15ns resolution
- 64-bit System Time Clock
- Frequency Compensated Method of System Clock adjustment
- 32-bit Addend and Accumulator Registers for Frequency Compensation.
- 64-bit Target Time Clock to Schedule Compare-and-Interrupt to the Intel XScale® Core
- Both Auxiliary Snapshots Trigger Event Interrupts to Intel XScale Core

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IEEE 1588* Hardware Logic Features of the Intel® Network Processor (cont.)

- Sync and Delay_Req triggered Snapshots on MII Interfaces
- GPIO triggered Snapshots on Auxiliary Interface
- Two Snapshot Registers, tx and rx, per Interface + Seq ID and UUID Registers for MII only.
- Timestamp Locking enable/disable.
- Special 802.3 'Tagged' MAC Frames Supported
- PHY & MII to 66Mhz Crossover Delay Catered for by Firmware.
- Traffic Analyzer Support

intel.

Clock Synchronization Algorithm in Software for the Intel® Network Processor

- $MasterClockTime_n = MasterSyncTime_n + MasterToSlaveDelay$
- $ClockDiffCount_n = MasterClockTime_n - SlaveClockTime_n$
- Where,
  - n – Sync message count
  - $MasterSyncTime_n$ - time at which Master sends a Sync message to a Slave
  - $SlaveClockTime_n$ - time at which Slave receives the Sync message
  - $MasterClockTime_n$ – computed by the Slave after the Sync message is received
- $FreqScaleFactor_n = (MasterClockCount_n + ClockDiffCount_n) / SlaveClockCount_n$
- Where,
  - $MasterClockCount_n = MasterClockTime_n - MasterClockTime_{n-1}$
  - $SlaveClockCount_n = SlaveClockTime_n - SlaveClockTime_{n-1}$
- $FreqCompValue_n = FreqScaleFactor_n * FreqCompValue_{n-1}$

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Summary

- Reliable nanoseconds to sub-microsecond time synchronization possible using standard inexpensive crystal oscillators.
- Integrated chip implementation saves on design BOM cost and PCB area.
- Targeted for various industrial control and measurement applications, e.g., industrial automation etc.
- Intel pioneering IEEE 1588* integration with Intel XScale® core-based architectures. Intel working closely with industrial control and measurement customers to ensure architecture, software model & implementation details mature with IEEE 1588 standard and meet customer demands.

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Progeny Systems
Engineering Solutions That Last Generations

Interfacing Mil Standard Equipment to an IEEE 1588 Enabled Ethernet Network

John D MacKay
Progeny Systems Inc.

16 September 2004

Progeny Systems

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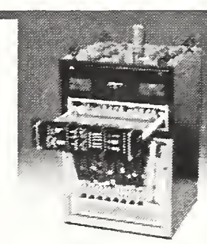
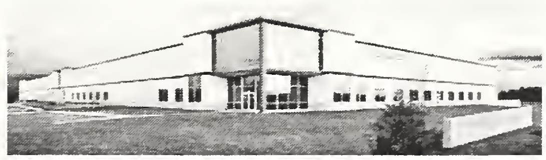
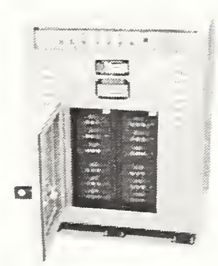
Engineering Solutions That Last Generations



- Small Business Department of Defense (DoD) Contractor for NavSea, NavAir, Air Force, and Others
- Primarily Work With Sonar Systems
- Prime and Sub-contractor With Lockheed Martin, General Dynamics
- Based in Manassas, VA
- Focus is to Develop Innovation for DoD





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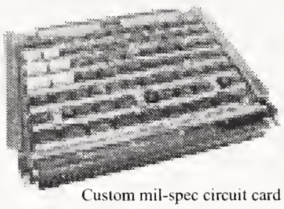
Motivations for Utilizing IEEE 1588 in a Mil Platform

Progeny Systems
Engineering Solutions That Last Generations

- Legacy Systems Are Stand-alone, Custom Made Mil Grade.
- When Implemented, Common Data Collection Was Not Needed
- Timing Sources Were Independent
- Introduction of Commercial Off-the-shelf (COTS) Equipment Permitted Access to Better Data Processing and Sharing
- Need Arose to Get a Common 'Bird's Eye View' of the Data Across Several Systems.
- Without a Common Time Reference, Data Reconstruction Is Difficult, in Some Cases Impossible.



Custom mil-spec circuit card

16 September 2004

Issues

Progeny Systems
Engineering Solutions That Last Generations

- Production Systems Counted in the 10's to 100s. There Is No Effort to Scale for Large Quantities.
  - Cannot Leverage 'Buying Power' for Cost
  - Cannot Drive Designs
- System 'Edge' Devices Interface to Custom Mil Interfaces
- Several Different Form Factors (PCI, PMC, VME, cPCI, etc)
- IEEE 1588 Tech Insertion Presents a Change to the System Infrastructure, Rather Than 1 Component. Questions Raised Include:
  - What are the System Performance Impacts?
  - Does the New Technology Increase System Cost Significantly?
  - Does It Impact Applications?
  - What Does It Take to Integrate and Test?

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Critical System Design Analysis
Test Impacts

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Many Systems Impacted by Infrastructure Change Are 'Ships Safety/Self Protect'.

Example: Forward Look Submarine Sonar System Used to Come to Surface

- New Technology Is Scrutinized for Impacts to These Systems.
- Failure Modes and Effects Analysis Is Performed on Any Potential Infrastructure Candidate
- Fail-over Mechanisms Need to Be Supported (Not Necessarily As Part of the Standard), and Minimize Impacts to System Architecture
- Infrastructure Changes Generate More Complicated Test, Retest Scenarios.

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Critical Design Analysis – Information Assurance (Security Levels)

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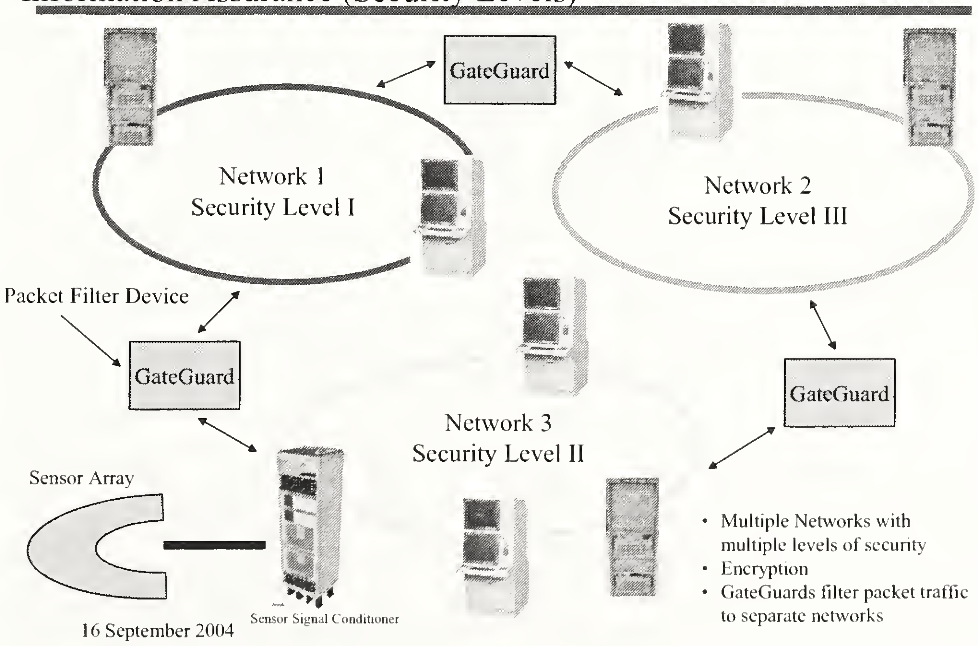

- Multiple Networks with multiple levels of security
- Encryption
- GateGuards filter packet traffic to separate networks

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Issues Raised by the Customer:

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The Ability to Achieve 10ns (or Lower) Is Not Beyond the Capabilities of 1588, but Will All/Some/Enough COTs Devices Be Capable of Achieving It?

- Will COTs NICs and Switches Replace Current Baseline Devices Without Infrastructure Impact?
- How Will Fail-over Work?
- What Is the Failover Time, in a Ships Safety Scenario, Provided the Data Is Still Processed in a Degraded Mode (Partial Array Processing)?
- Will Cots Cards Provide a Clock to Source the Digitizers?
- How Will Performance Be Affected By Information Assurance Requirements?
- How Does 1588 Deal with IPV6?

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Seeking to Insert IEEE 1588 Into System Starting With Sub-system Components....

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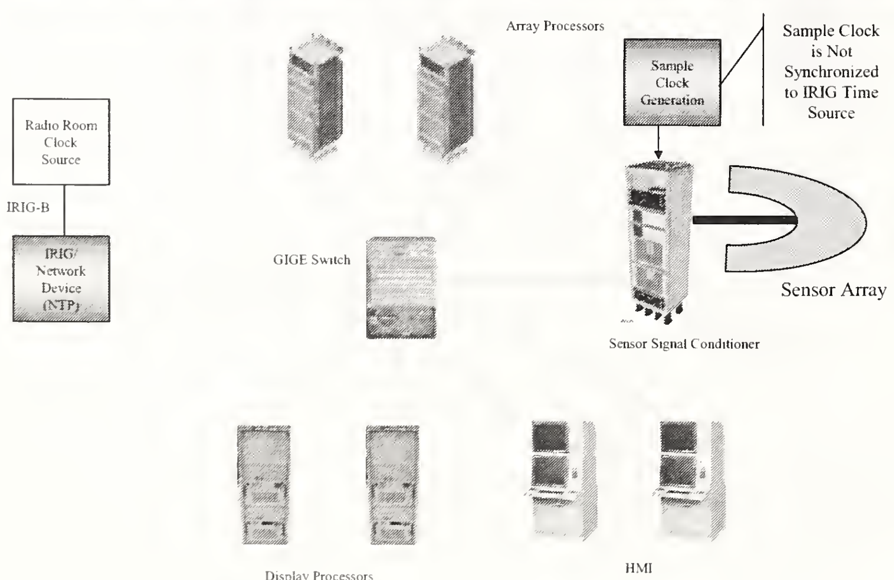

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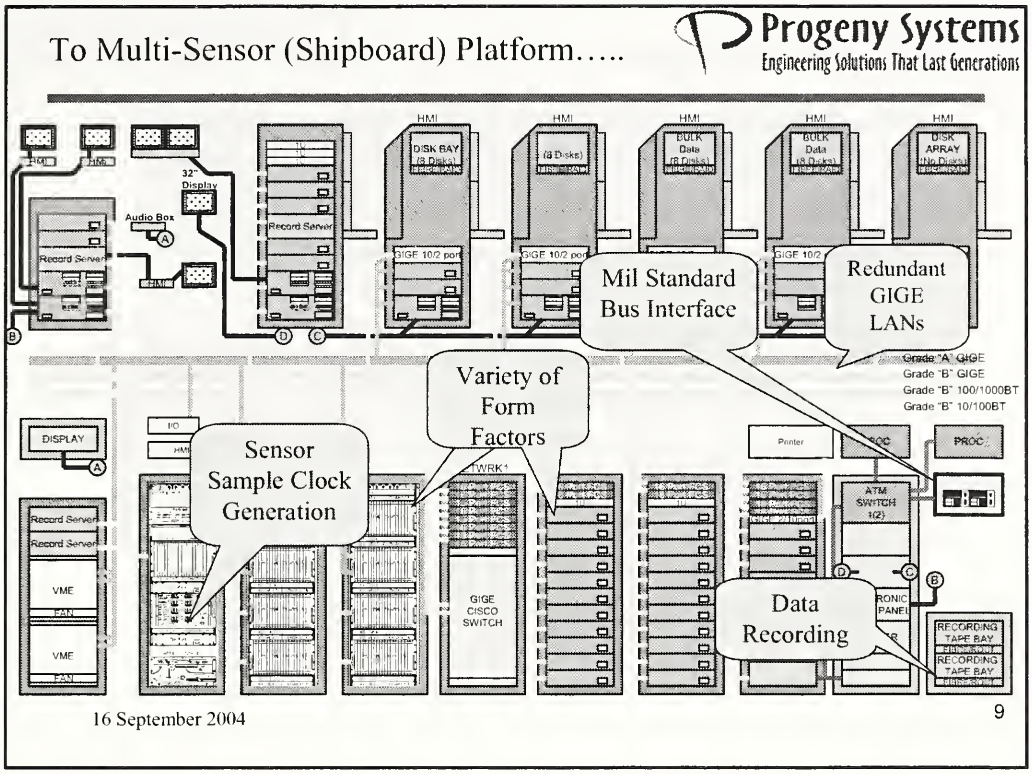
To Multi-Sensor (Shipboard) Platform…..
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Mil Standard Bus Interface
Redundant GIGE LANs
Variety of Form Factors
Sensor Sample Clock Generation
Data Recording
Grade "A" GIGE
Grade "B" GIGE
Grade "B" 100/1000BT
Grade "B" 10/100BT
DISPLAY
Record Server
VME
FAN
GIGE CISCO SWITCH
ATM SWITCH
RECORDING TAPE BAY
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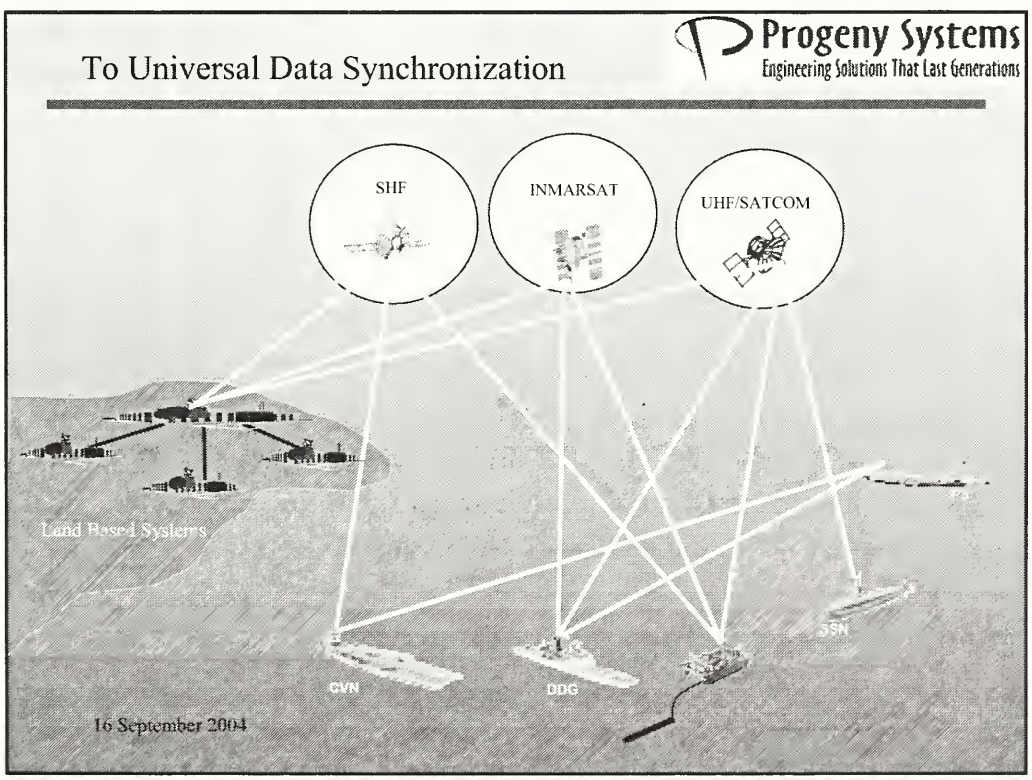
9


To Universal Data Synchronization
Progeny Systems
Engineering Solutions That Last Generations
SHF
INMARSAT
UHF/SATCOM
Land Based Systems
CVN
DDG
SSN
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Data Synchronization

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Data Sampling Synchronization Is the Underlying Requirement:

- Several Processing Units Are Needed to Sample Data Coming Into an Array. They Must Sample the Data Synchronously – the Sample Clock Edges Must Be Synchronous to Within 10ns.
- At a Higher Layer the Data Buffers Must Have Identical Timestamps So That They Can Be Processed Together.
- At a Higher Layer Still, the Processed Data Needs to Be Timestamped to Correlate to Data From Other Arrays

These 3 Timestamp Requirements Have Been Implemented in Various Ways in the Past, Typically As Separate Solutions.

- They Are Not Always in Sync
- They Use Different Standards
- They Use Proprietary or Obscure Standards

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Mechanisms for the Insertion of IEEE 1588 Into Mil Systems

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- Some (But Not All) Agencies Support a Planned Approach to Technology Enhancement. These Use:
  - Research Funding Vehicles
    - Small Business Innovative Research (SBIR)Program
    - Broad Agency Announcements
  - Technology Insertion for existing COTS systems
    - 'COTS Technology Refresh' Cycle Exist to Introduce System Improvements
- Need Is Identified by Performance Requirements of Baseline Systems
  "Problem Solving"

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The DoD ASTO Process – Rapid COTS Insertion

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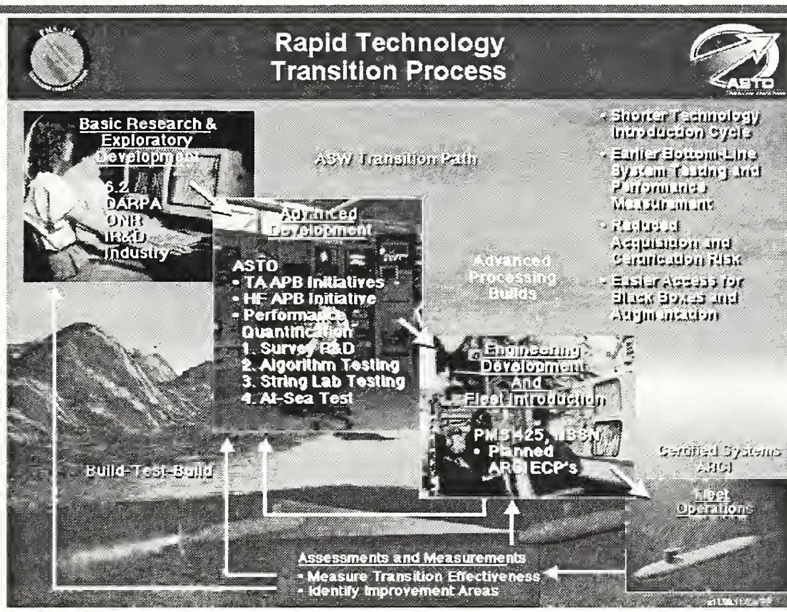

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System Technology Insertion Impacts

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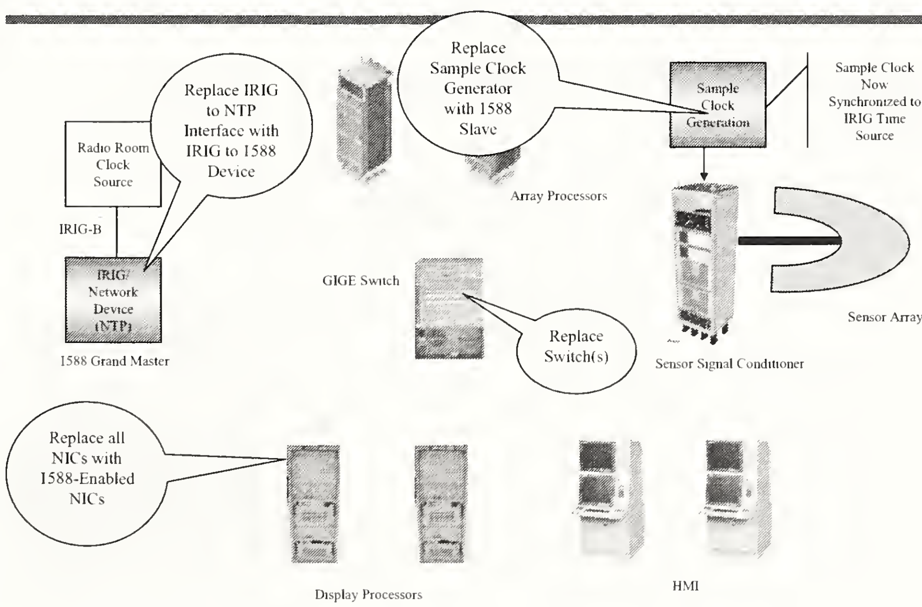

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Rapid COTS Insertion Process

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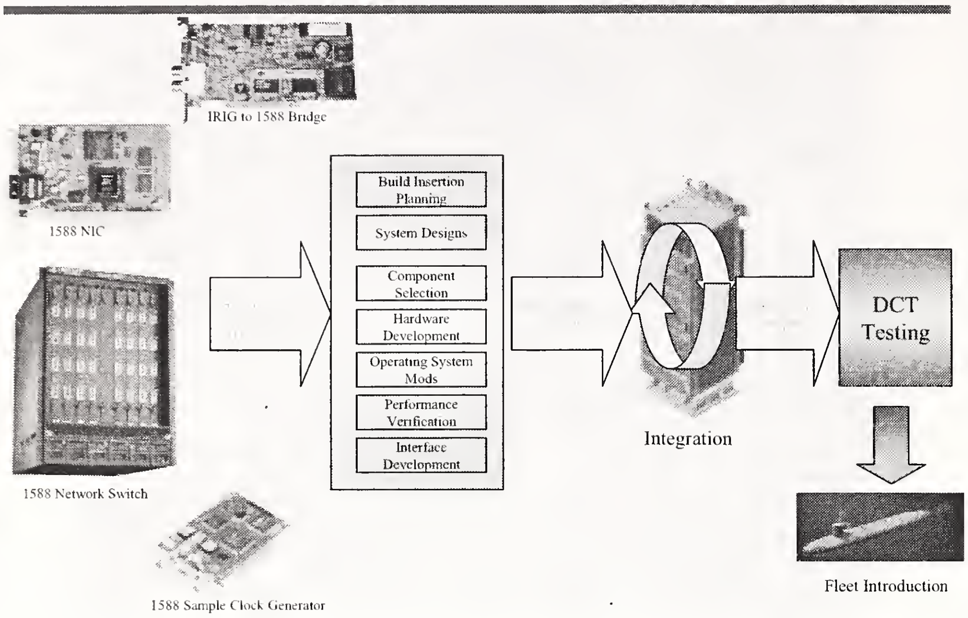

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MIL-STD-1553 Use Case

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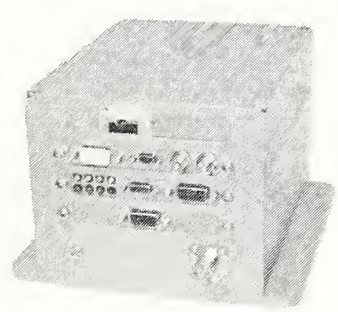
Aircraft Internal Time-Division Command/Response Multiplex Data Bus

- In use since 1973
- Widely applied.
- 'B' version created to specify the electrical interfaces explicitly so that compatibility between designs by different manufacturers could be electrically interchangeable.
- The Department of Defense chose multiplexing because of the following advantages:
  - Weight reduction
  - Simplicity
  - Standardization
  - Flexibility
- Can utilize more than one data bus on a vehicle.
  - Isolate a Stores bus from a Communications bus
  - construct a bus system capable of interconnecting single bus could accommodate



Progeny 1553 to Fibre Channel Bridge

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Mil 1553 Data Encoding

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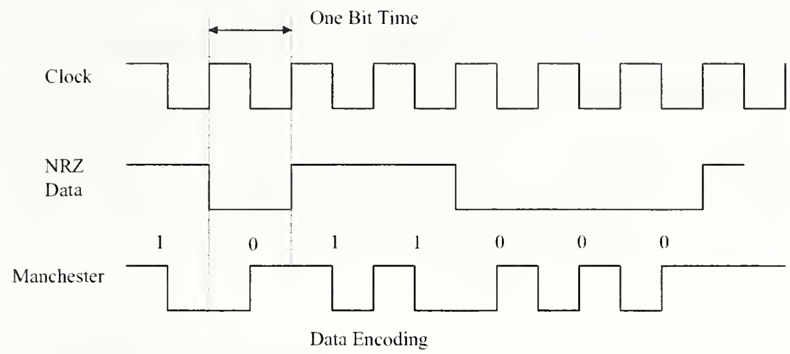

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Bus Architectures

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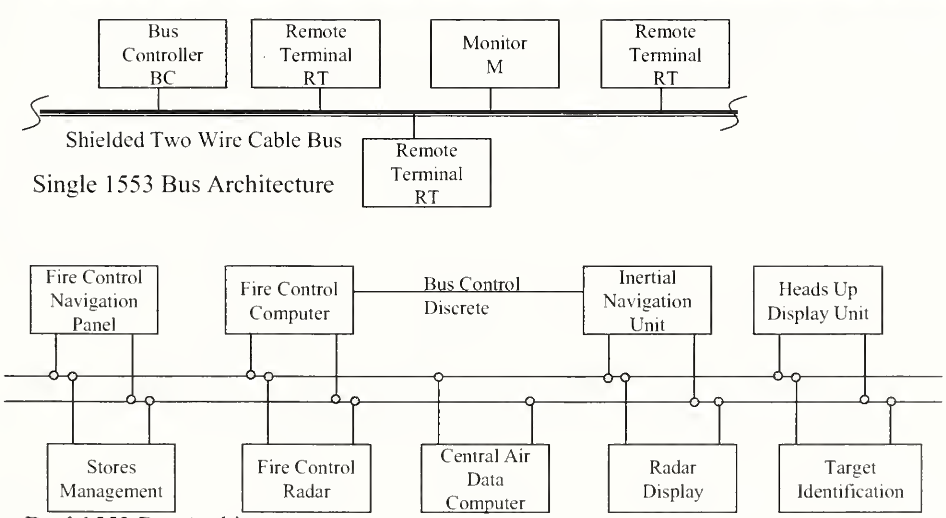

Dual 1553 Bus Architecture

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Interfacing 1553 to an IEEE 1588 Network

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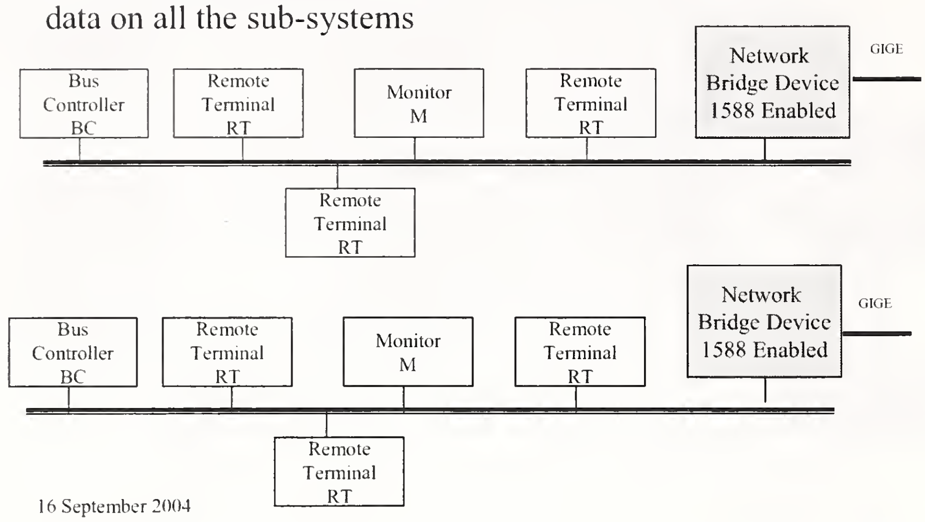
A new requirement is established to time synchronize the data on all the sub-systems



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Interfacing 1553 to an IEEE 1588 Network

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Initial Analysis

- The 1588-enabled Network Provides the Source of Time
- A 1553 to Ethernet Bridge Must Be Designed to Connect the Interfaces Electrically, and to Translate the Data
- As a Separate Sub-system, Each Legacy Bus Generated Independent Time Data
- A Single Node on the Bus Was the Time Data Source
- Time Data Is Separate From the Clock Used in the 1553 Interface

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Implications

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- The Legacy 1553 Busses Need to Be Able to Support a New Node, Both in Software and Hardware
- The Previously Unconnected Systems Must Be Able to Co-exist on Ethernet
- The Legacy Busses Use an Internal Time Source That May Be Stand-alone, or based on External Interfaces
  - The new bridge can't serve time to the 1553 devices
- The Impact:
  - Wiring and Software Changes May Be Required for Legacy Devices to Recognize New Node – Costly Development & Integration, Then Significant Testing for the Mil System

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Options

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1) Revise or replace the components in the system that serve time to act as timing slaves instead using existing protocol

Pros:

Impact to the 1553 system may be minimal – a single node might be the only device affected

1553 to Ethernet Bridge would be a simple end-device for PTP

Cons:

The 1553 clock requirements may exceed the 1588 system performance

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Options

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Engineering Solutions That Last Generations

2) Implement 1588 on the mil 1553 bus, replacing all time services with PTP.
   - The 1553 to Ethernet bridge would become a PTP Bridge
   - Pros:
     - If the 1553 clock requirements exceed the rest of the network, the 1553 clock can become the Grand Master Clock
   - Cons:
     - The development and integration effort may be significant

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Conclusions

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- The Impact of a Implementing a Different Time Standard or Protocol on a Legacy Mil System Can Be Dramatic and Costly
- The Introduction of a COTS Baseline in Mil Hardware Systems Provides a Significant Enabler to New Technologies Such As IEEE 1588
- Even When Such an Architecture Exists, System Analysis and Planning Is Still Required.
- Some Agencies Recognize This and Have Built Tech Refresh Processes

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Use Case - driven 'Wish List' for IEEE 1588 Devices

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- 1ns Synch Performance (or Better) to Meet Requirements Across a Variety of Applications
- Programmable Logic Cores and Chipsets
  - Allow Us to Make a Card Like the COTS Cards
  - Ideal to Be a FPGA Core for the 10-20ns Performance Area
- Capability to Fail Over From 1 Master to Another Without Significant Loss of Data
- COTS Network Devices That Are Plug-in Replacements to Current Devices
- Interface Signal Cards for 'Edge' Requirements - for Digitizers and for Incoming Time Reference

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Automatic Test Systems using LAN-based Synthetic Instruments and the role of IEEE-1588

John Stratton
Agilent Technologies, Inc.
Synthetic Instruments Marketing/Planning Manager

Agilent Technologies

Where test systems got started

- **Manual control of test instruments and data recording**
  - Operator differences (training, settings, data input errors, etc.)
- **Automated measurements**
  - No *Standards* for control
  - No *Standards* for timing and triggering (Event triggering)
  - **BCD (Binary Coded Decimal), HPIB (Hewlett Packard Interface Bus), RS-232, Etc.**
  - **Each instrument manufacturer had their own way of programming their instrument**
  - **10 MHz synchronization standard (frequency domain instruments)**

Software was becoming a larger part of the Automatic Test System (ATS)

•**Benefits of software control**

- **Repeatability – The instrument is set up in the same condition every time.**
- **Accuracy – The resulting data is stored/printed without transcribing errors.**
- **Speed – Higher throughput testing due to minimal operator intervention**

Standards are needed for the benefits of automation to succeed

•**Communication interface – GPIB has been the standard for 25+ years.**

•**Software interface – Standard Commands for Programmable Instruments (SCPI), VXI plug-and-play have been around for 15+ years**

•No computer standard – Driven be commercial needs

•No Operating System (OS) standard – Driven by computer manufacturers or custom OS

Today's *Open-standard* choices for synthetic instruments

All these choices are based on the backplane of a commercial computer architecture standard

SCXI VME
PCI C-PCI

What's Next?

PCI EXPRESS

INFINIBAND

Considerations of Card cage modularity

Reduction in Common components–Potentially increase in reliability

Power Supply – If specified power is not ideal DC to DC conversion may be required. A complete analysis of the current and future needs must be assessed for optimum selection (too much power equals under utilization).

High Speed Backplane - A very cost effective use of computer industry standards to drive down development costs and time. High speed trigger bus. However, these *Standards* are neither backwards compatible or Stable (Forwards compatible).

Computer processing and display – Can take advantage of the continuing downward cost of PCs. However, the embedded PCs are usually multi-generations behind current of-the-shelf PC products and 5-10X more expensive.

Compact Instrument Design – Purchase only what is required. Add modules as the need changes. Many vendors are available for low frequency components. However, not all functionality is available in all formats (especially RF & μwave) forcing multiple card cage types or the use of old products.

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DoD drives cost and size reduction

First attempt at standardization (Goals)

Benefits

- **Smaller form factor – Instruments on a card**
- **Less cost – Elimination of front panel, computer, common power supply and display**
- **Higher Reliability – Fewer parts equal fewer failures**
- **Long support life – Defense test systems need to be around for 20+ years.**

Results

- **VXI – Based on Computer VME architecture for instruments**
- **SCPI/VXI PnP – software communications standards**

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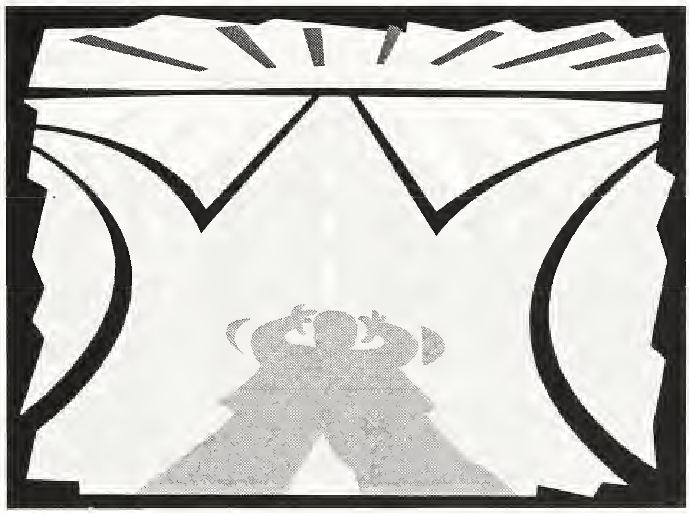
Where do we go from here?



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The DoD would like with Synthetic Instruments to address: (Current Goals)

1. **Size reduction**
   a. Reduce redundant **(same or similar) functional blocks (Digitizers, down-converters, microprocessors, displays, etc.)**
2. **Total Cost of Ownership reduction**
   a. **Elimination of redundant hardware/software will** reduce total acquisition cost.
   b. Fewer unique line items **will shrink logistic footprint (spares, support systems, training, interoperability, etc.)**
   c. Common module definition **should promote competition.**
   d. **Simplified hardware modules will support backwards and forward compatibility (**Protect the TPS**) of test systems**
3. Faster fielding **of new test systems**

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Should technology drive module partitioning?

2x performance and/or ½ the cost for the same performance

Digital	D/A and /or A/D Conversion	Analog	RF/µwave /mmwave
•DSP Speed •µprocessor speed •Memory size and speed *~18 Months*	•Higher sample rate for a given dynamic range •Higher dynamic range for a given sample rate *~24-36 Months*	•Higher performance •Lower cost *•This area is being squeezed out by D/A and A/D bandwidth growth which will support SI goals.* *~24-36 Months*	•Asymptotically approaching the performance limits •Advances in size and cost are key *~36-84 Months*

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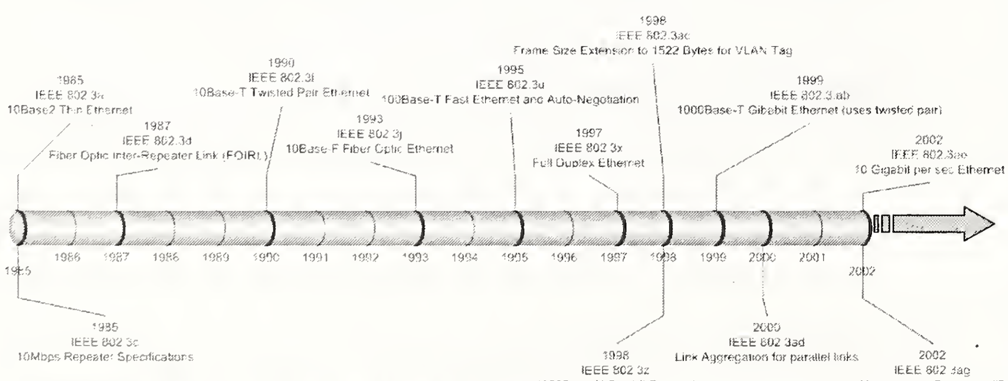
Ethernet History
Communications interface that will last
Supports *all* computer operating systems



IEEE-1588 for Inter-module Timing, Synchronization, and Triggering (where appropriate)

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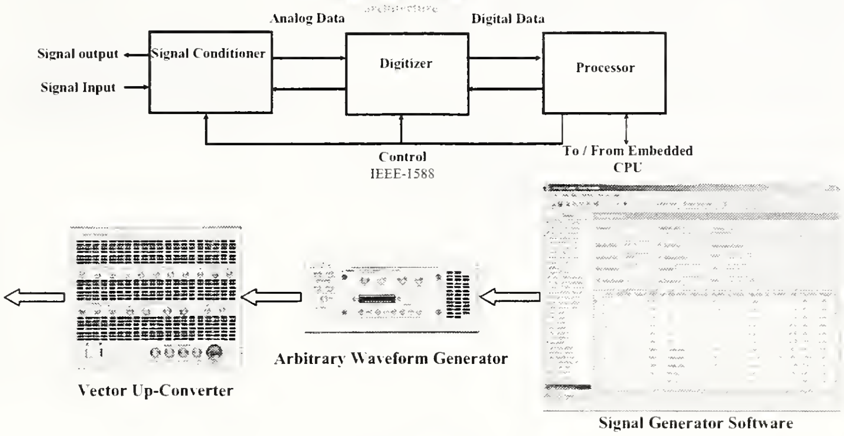
What is a Synthetic Instrument?

Based on SI working group definition

• **A collection of hardware and software modules that can be concatenated together to emulate a standard instrument.**



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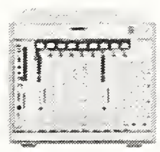
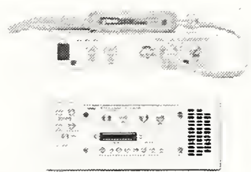
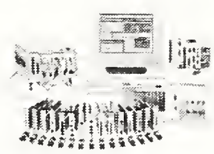
What is a Synthetic instrument module?







•An *Elemental* building block of a larger measurement system.

- SI modules used in reconfigurable applications
- Simpler the building block, the easier to upgrade
- Standard interfaces

•Application software is *external* to the SI module

•Characterization software - characterize the measurement path to provide metrology grade performance.

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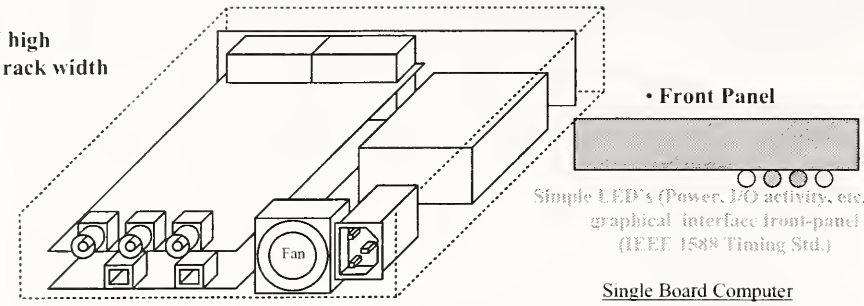
Synthetic Instrument Module Physical Definition of LAN Based Module:

EIA Standards

- **1U high**
- **½ rack width**



• **Front Panel**

Simple LED's (Power, I/O activity, etc.) with graphical interface front-panel (IEEE 1588 Timing Std.)

**Rear panel I/O:
Ethernet ,
Trigger/Arm,
Power**

Single Board Computer

1. Intel PXA255 processor 400MHz
2. 32-64MB flash memory
3. 32-64MB SDRAM
4. 10/100 BaseT Ethernet interface
5. USB On-The-Go 2.0 capable of full speed communication (host and device)
6. Host to PCI bridge
7. Internal power supply

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LXI: LAN eXtensions for Instrumentation

Industry standard: LAN & AC

- Fast, cheap, ubiquitous.
- No expensive cards, cables or mainframes
- LAN in forward compatible
- **IEEE1588 Timing and synchronization Standard**
- Industry Consortium: Open Standard

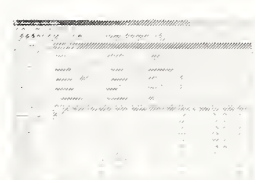
Compact, standard sizes

- Typically ½ the size of rack and stack
- ½ rack (or full), 1U, 2U, 4U high
- Depths: 13 ½, 16 ½, 25 inches

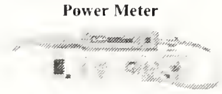
Best Value

- No expensive card-cage or slot 0 computer
- Rack & Stack performance and measurement science
- Easy to build product environment

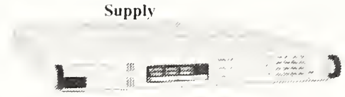
Agilent Synthetic Instruments



Power Meter



Power Supply



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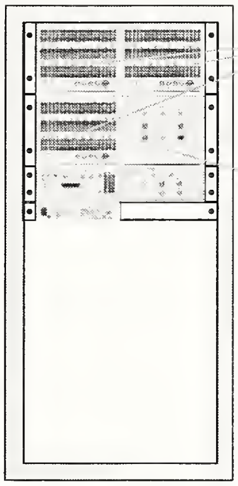
LXI Synthetic Instruments vs. Traditional Instruments

Re-Configurable, Re-Usable, Less Rack Space!



RF Stimulus Group

Independent Synthesizers: 3

Frequency: 3 MHz to 40 GHz

RF Measurement Group

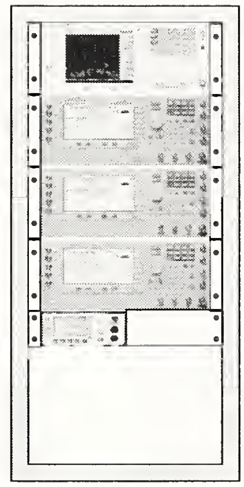
"Spectrum Analyzer"

Power Meter (2 channel)

Frequency 100 Hz to 40 GHz

Expandable to 220 GHz with ext mixers

Frequency and time domain analysis



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Benefits of IEEE-1588 as a Standard for LAN-based instrumentation

Simple cable design for high channel count data acquisition -LAN vs. Bundle of matched cables

Potential elimination of distribution amplifiers

-May require better timing resolution (~1 nanosecond))

High throughput measurements using *time bombs*

-parallel vs. sequential

-removal of software timing wait-states

Lower cost of ownership

- Test and measurements assets based on industry standards

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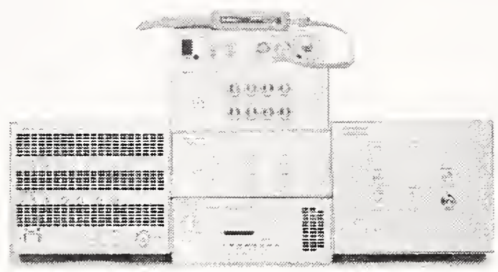
Agilent moves industry's best technology into Synthetic Instruments.

Questions?



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IEEE 1588 in Telecommunications Applications

Dave Tonks
Semtech, Advanced Communications Division
Southampton,
UK

SEMTECH

IEEE 1588 can be used in telecom applications if......

Telecom networks have many areas where a common time base is needed. IEEE 1588 could be very useful, but the following issues are a barrier to its adoption :

- Telecom paths not jitter-free and boundary clocks not available
- PTP messages too bandwidth-hungry for some applications
- No redundancy
- Time-To-Live = 1
- Authentication?

This presentation uses a couple of example applications to highlight these issues and either points to suggestions made by the working parties or suggests new solutions.

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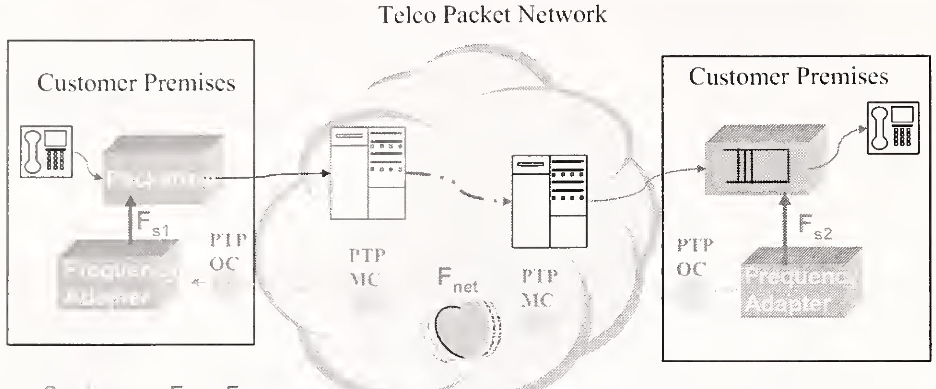
Example 1: IEEE 1588 supporting Circuit Emulation Service

A network clock is used globally for synchronous services



Goal: $F_{s2} = F_{s1}$

Problem: Adaptive-clocking is slow to lock and slow to follow drifts, and is also vulnerable to packet errors and jitter.

Fix: Use PTP to get network clock in each customer premises from which service clock can be generated.

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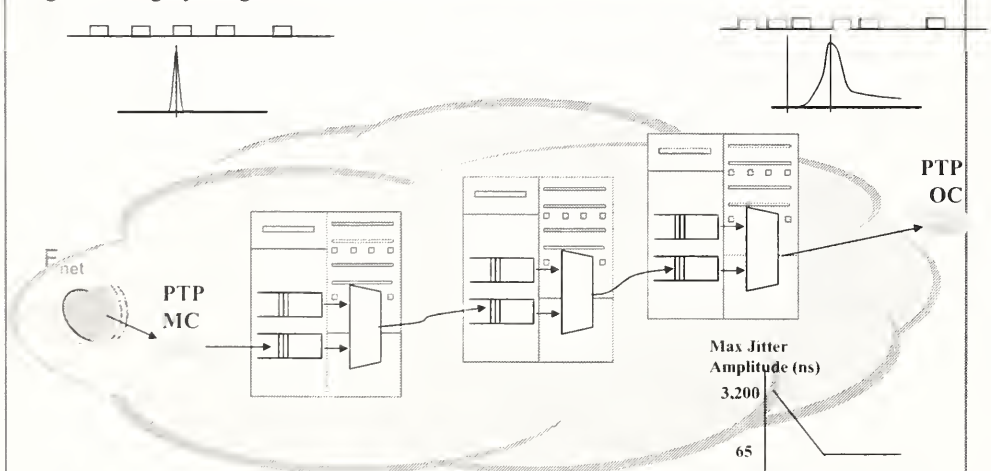
The delay jitter issue:

Delay jitter: Lack of boundary clocks means inter-packet interval changes from regular to highly irregular…..



Goal: OC output should be accurate and stable

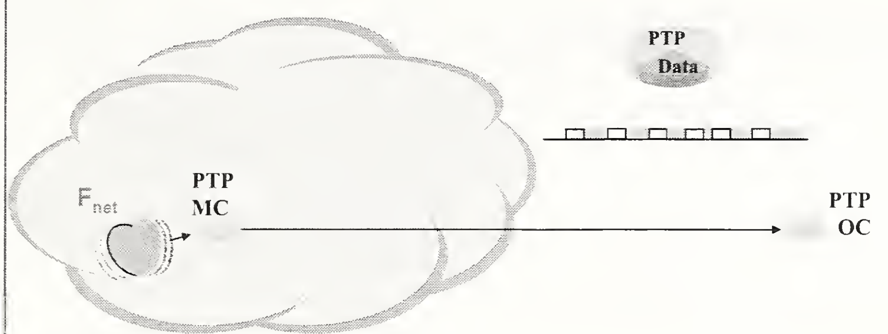
Problem: random delays spoil regularity of timing packets

Fix: use strong filtering in OC with stable local oscillator

SEMTECH

The bandwidth consumption issue:

Overcoming delay jitter requires higher rate of PTP messages which, on low-speed telecom links, consumes too much bandwidth and in any case is too expensive when charged per-bit.......



Goal: $\sum BWptp << \sum BWdata$

Problem: long PTP messages, sent at higher rate, consume too much bandwidth

Fix: reduce message size

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Semtech's proposal for short messages.....

versionPTP	2
versionNetwork	2
Subdomain name	16
messageType	1
Information about source	11
Control	1
Flags	2
reserved	4
originTimestamp	8
epochNumber	2
currentUTCoffset	2
Information about Grandmaster	20
syncInterval	1
Information about local clock	6
Information about parent	9
estimatedMasterVariance	2
estimatedMasterDrift	4
utcReasonable	1

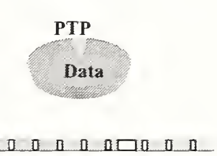
Present format of Sync Message (94 bytes)

versionPTP	2
versionNetwork	2
control	1
subdomainNumber	1
flags	1
shortSequenceID	1
originTimestamp	8
syncInterval	1

Proposed short Sync Message (17 bytes)

Mod to normal Sync Message:
16-byte subdomainName mapped to 1-byte subdomainNumber

Result:



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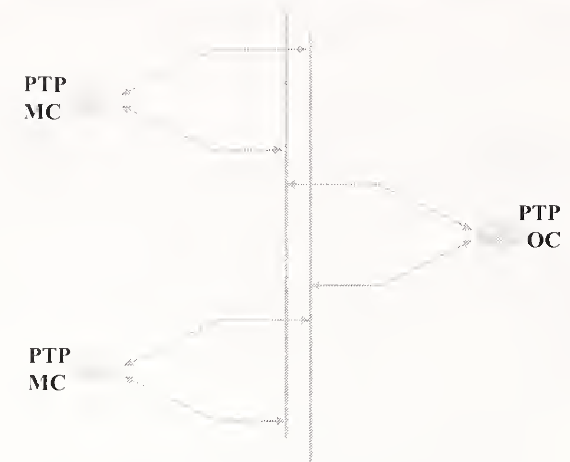
The redundancy issue:

Telecom clock must always be available, even during component or network failure……



Goal: High-availability through no single point of failure
Fix: add redundancy support

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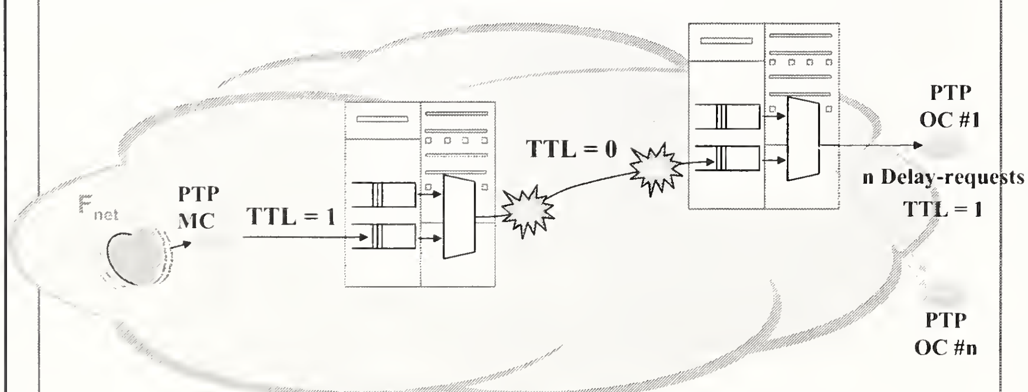
The multicasting issue:

Multicasting is used but is limited to one sub-net, with the premise that a boundary clock controls the next sub-net; but (1) telecom networks will not have boundary clocks, so PTP is blocked, and (2) slaves will be swamped by higher rates of delay messages…



Goals: To get through! To avoid swamping slaves.
Fix: Avoid high rates of multicast messages, maybe use unicast for short delay messages.

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Example 2: IEEE 1588 could support OSS

Operations Support Systems would benefit from a network-wide time base:

- Billing activities in high-speed all-packet network will develop beyond today's distance/duration/tariff or subscription models:
  - For each packet, take note of type-of-service (eg, video, on-line gaming),
  - Take note of sum of packet-durations/service
  - Charge customer; pay content providers
- SLA-compliance checking:
  - Report detected anomalies, failures
  - Cross-check with similar report from CPE (needs accurate timestamping in CO and CPE)
  - Schedule maintenance
  - Credit customer

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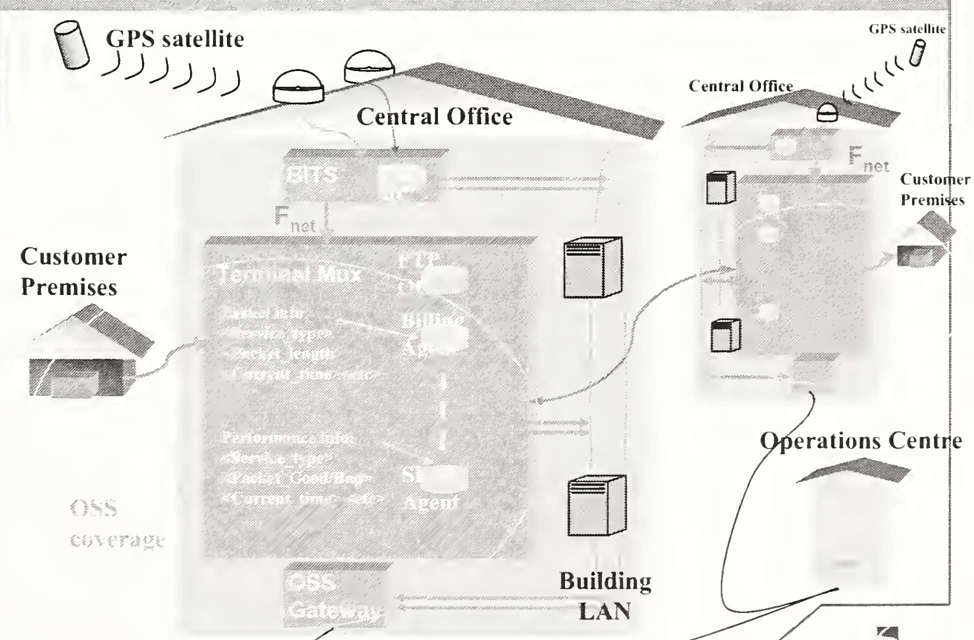
IEEE 1588 supporting OSS:



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Summary

If the issues which have been highlighted can be solved, PTP offers a simple way to get a common time base across a network with much better accuracy than present-day alternatives.

- Issue: Excessive accumulation of delay jitter caused by lack of boundary clocks:
  - ✓ Solved by long-term filtering, but needs faster message-rate if local oscillator clock cost is to be kept down
- Issue: Bandwidth consumption makes PTP expensive:
  - Higher message rate consumes more link bandwidth, strangling low-speed links and costing excessive amounts on higher-speed links.
  - ✓ Fixed if shorter messages are used.
- Issue: Reliability concerns avoided if redundancy support added
- Issue: Routing/bandwidth compromise (multicast issue):
  - Need to define a way round
- Issue: Authentication of time source:
  - Need to define a way round, if not guaranteed by network topology.

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Telecom Update to IEEE1588 Workshop

Sept 29 2004

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Agenda

Recap of key messages into Telecom

Summary of IEEE1588 past year events in Telecom - Public Networks

Summary of Telecom IEEE1588 key needs – Nortel view

IEEE1588 “Ethernet MAC distinguishable” items for PAR

Telecom Next Steps

Q&A

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RECAP: Telecom Drive for IEEE1588

Problem Statement

Transition is now occurring from circuit to packet in the metro
Ethernet edges are replacing traditional E1/T1 circuit demarcation
Precision timing typically reduces cost of time sensitive applications
Timing sensitive endpoints being impacted are Cellular,Broadband DLC, and SME Enterprise

Timing sensitive services that used the circuit timing references (e.g. Sonet) are difficult to transition to Ethernet edges without a packet-based precision timing reference

Solution Proposed

Nortel Networks proposes that IEEE1588 be adapted for this need. Positioned as a precision timing service over Metro Ethernet demarcations into Wireless, Broadband, or Enterprise
Slight enhancements to IEEE1588 standard are proposed for these Metro Ethernet services
1588 timing payloads are extensible to any frame/cell packet transport
Does not replace NTP, can interwork with it

- ***IEEE1588 over Metro Ethernet for Wireless, Enterprise and Broadband***
- ***IEEE 1588 across a Ethernet UNI enables timing sensitive services to utilize Metro Ethernet solutions***

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RECAP: Metro Ethernet Timing Packet Service Dimensions

Precision Timing Service components

- Timing Sourcing edge point(s)
- Timing Recovery/Adaptation edge points
- Timing Sensitive Service edge points

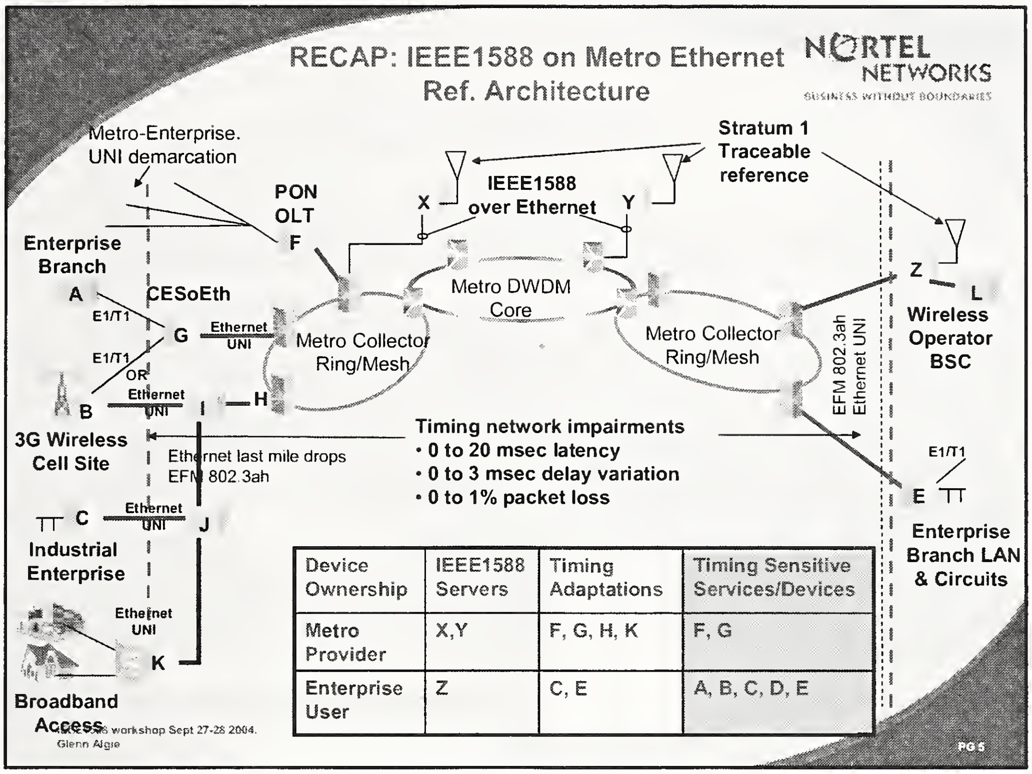
Management and ownership options

- Enterprise managed service/device
- Metro Provider managed service/device
- Hosted Service provider service/device

Variety of Metro Ethernet Network Impairments

- Metro core vs. Metro collector & edge, Ring vs. Mesh vs. Star topologies
- Ethernet over 802.17 (RPR) vs. Ethernet over Sonet vs. Ethernet over WDM vs. others
- Technology & Architecture combos have performance impact on IEEE1588 PTP flows

- ***Precision timing service components span ownership boundaries***
- ***Capture of boundary conditions and predictable performance in progress***
- ***This is a multi-vendor timing solution across the Ethernet UNI for MEF to approve***



Device Ownership	IEEE1588 Servers	Timing Adaptations	Timing Sensitive Services/Devices
Metro Provider	X,Y	F, G, H, K	F, G
Enterprise User	Z	C, E	A, B, C, D, E

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Telecom - Public Networks
Summary of IEEE1588 relevant events (2)

IEEE1588: Sept 2003 Telecom proposal- Nortel Networks, sub second rate & L2 multicast/Ethertype needs

ITU-T SG15 Q13: Nov. 2003 proposal made – Zarlink/Nortel, Outcome: work item is active, Circuit emulation over packet use case focused

NIST T1X1 Sync workshop: Feb 2004, a number of IEEE1588 proposals and discussions, Outcome: No push back, Raised awareness for IEEE1588 into Telecom, gained some Telecom Timing vendors support & visibility

T1X1.3: Actively working on "Synchronization of Packet Networks" report (Nortel, Zarlink have been contributing to this work),

T1X1.3: Mark Jones of Sprint held 2 public conference calls, objective to collect Telecom sync initiatives, minutes for each, Mar 10 - May 20

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Telecom - Public Networks
Summary of IEEE1588 relevant events (2)

Continued

802.3 Ethernet First Mile, March 2004 Plenary,

- Gibson Guitar sponsors Plenary entertainment evening – Guitar with RJ45: proprietary synchronous music MAC.,
- informal meet held Consumer Electronic vendor teaming around Synchronous Ethernet for the Residential LAN. Karl W. of Siemens presents Industrial use case, 1588 timestamp like framing at 1000's/second rate.

802.3, July 2004 Plenary: Successful launch for "Residential Ethernet" study group. Residential Ethernet = Synchronous Ethernet

MEF: Aug 2004, propose as option in "Ethernet UNI", Telecom sponsors

IEEE1588: Sept 2004 workshop @ NIST, include sub rate and L2 multicast in 1588 PAR

802.3 Sept Interim: Residential Ethernet study group first meet Sept 29 –Oct 1

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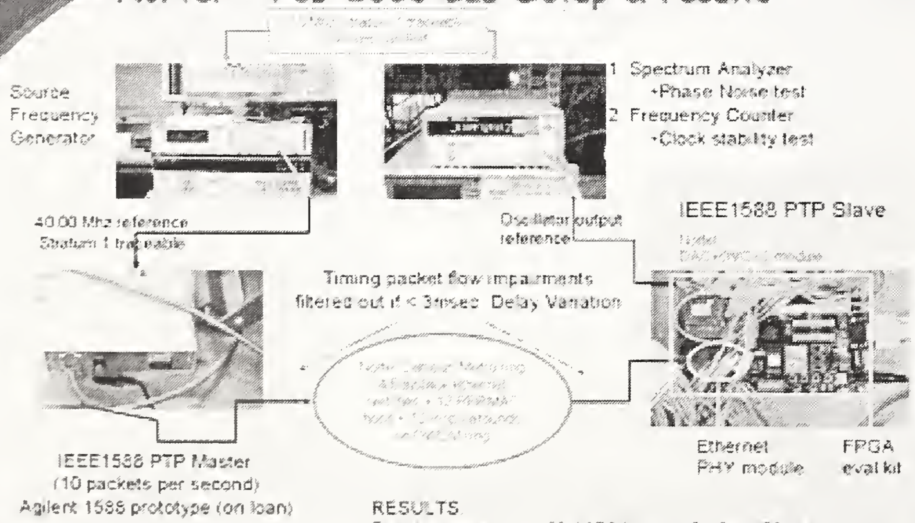
Nortel - Feb 2003 Lab Setup & results



RESULTS

Requirement	63.8976 Mhz +/- 3.19hz (50 ppb)
Measured	63.89759944 Mhz +/- 0.24 hz (4 ppb)

Phase Noise over (1-1Khz) meets 3GPP BTS dBc/hz needs

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Sprint Conf Call & Minutes: May 20 2004

Sprint: Mark Jones, Chuck Norman, Jim Black
Nortel: Glenn Algie, Michel Ouellette, Michael Mayer, Richard Brand
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Key item:
Uncertainty over possible overlap between scope of T1X1.3 TR on sync in packet networks and the new ITU-T draft Rec. G.pactiming - interest in both groups to work together, possibly generate another liaison at July T1X1.3 meeting

Action: Follow up with Mark Jones needed on progress

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Sponsors for MEF Aug 9 IEEE1588 on "Ethernet UNI"

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Summary of Telecom IEEE1588 key needs – Nortel view

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1. As optional overlay, define a IEEE1588-compact (64 byte total) run time compatible message format
   - Remove non-timing related material from Ethernet payload (IEEE 1588's origins are in industrial control applications where machine OAM information is included in the current protocol payload definition. This OAM info is not needed for telecom.) The objective of this change is to get the payload down to 64 bytes.
   - Work the July 2004 Semtech submission to 1588 task group
2. Get L2 Multicast OUI and/or Ethertype assigned – IEEE SEC
3. Increase rate at which timing packets are sent

   Add backward compatible "sub interval" field to identify if "interval" is seconds or milliseconds
   - 10 PPS has shown good results in lab tests
   - 100 PPS is fastest rate expected
   - x000 PPS could fit a 802.3 Residential Ethernet Study Group proposal
4. Allow Vlan tagging,

NOTE: Ethernet standards are active in "stacked" Vlan ("Q inQ) and "stacked" Ethernet MAC (MAC in MAC).

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"Ethernet MAC distinguishable" items for IEEE1588 PAR

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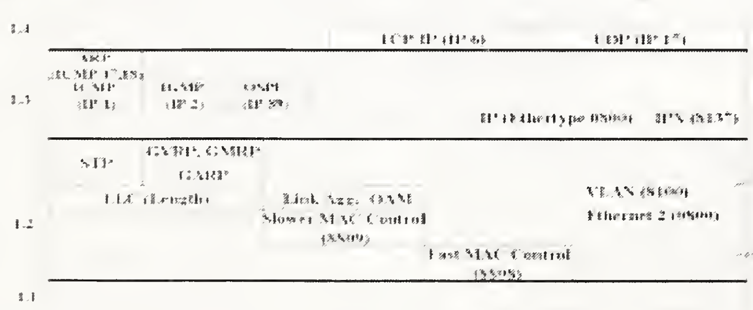

Propose: Reserve "non-link constrained" Multicast ID

Consider: Impacts of 1588 new Ethertype

Objective: allow simpler Ethernet switch/bridges (Multicast aware and non multicast aware) ability to uniquely identify, steer, replicate and prune the IEEE1588 precision timing flow based strictly on Ethernet MAC parameters.

To date we are limited a VLAN mapping approach, this is not sufficient for a MEF proposed mandate for IEEE1588 on "Ethernet UNI"

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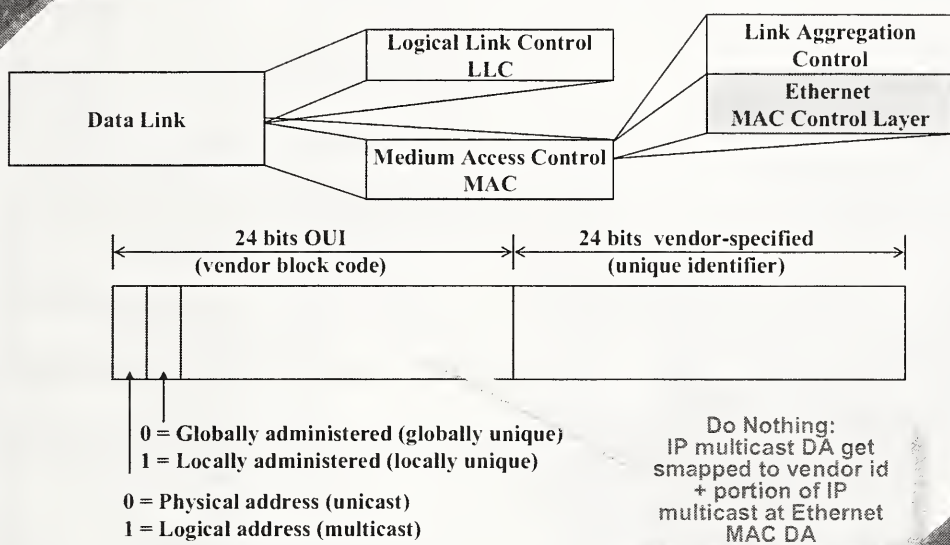
Ethernet MAC addressing & control



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Telecom - Key Next Steps

Must have a short term, Jan 05, public deliverable from the IEEE1588 PAR to establish the proposed IEEE1588 mandate over Metro Ethernet Forum "Ethernet UNI".

- Secure a IEEE OUI "non-link constrained" multicast id
- Secure a Ethertype, if needed
- Issue 1588 voter approved paper similar to the IEEE1588 over IP appendix
- Go back to MEF for vote to "mandate IEEE1588 use across the 'Ethernet UNI', IF the User end point service/application/device requires a precision time reference".

Must increase Telecom awareness and Telecom vendor alignment towards IEEE1588.

- "Ethernet UNI" rolls in 2005 into Telecom – Public Networks
- Watch for timing sensitive service roadblocks, ie Wireless, Enterprise and Broadband end point services/applications/devices transitioning connectivity from Metro Sonet/SDH/Circuit to Metro Ethernet

Must seek out at least one, prefer 2, Metro Provider volunteer(s) to do a 6-12 month"Soak" on a time distribution solution.

- Eg. Bell Canada, SBC, Bell South, Verizon....France Telecom....NTT Japan... etc
- Leverage Plug fest like 1588 test benches & protocol analyzer
- Accessible by the vendors to pull regular stats
- Issue public report to 1588 and to selected Telecom forum

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